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VOLUME XXVIII. 1934-1935.

Containing the Report of the Thirty-Second Annual Conference, held at Sheffield, July 2nd, 3rd, 4th, and 5th, 1935; also Papers and Discussions presented at Branch Meetings held during the Session 1934-1935.

Edited by T. Makemson, Secretary.

Institute of British Foundrymen.

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THE INSTITUTE OF BRITISH FOUNDRYMEN

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AWARDS 1934-35

THE "OLIVER STUBBS" GOLD MEDAL

No Award was made in 1935.

The Oliver Stubbs Medal has been awarded as follows:—

1922.—F. J. Cook, M.I.Mech.E.
1923.—W. H. Sherburn.
1924.—John Shaw.
1925.—A. Campion, F.I.C.
1926.—A. R. Bartlett.
1927.—Prof. Thomas Turner, M.Sc.
1928.—J. W. Donaldson, D.Sc.
1929.—Wesley Lambert, C.B.E.
1930.—James Ellis.
1931.—John Cameron, J.P.
1932.—J. E. Hurst.
1933.—J. W. Gardom.
1934.—V. C. Faulkner.

MERITORIOUS SERVICES MEDAL

1935 Award to Mr. H. BUNTING.

"For valuable services rendered in his capacity as Secretary of the East Midlands Branch for over twenty years, and for his work as a member of Committees and in other capacities."

The Meritorious Services Medal has been awarded as follows:—

1933.—F. W. Finch.
1934.—J. J. McClelland.
1935.—H. Bunting.

DIPLOMAS OF THE INSTITUTE

were awarded to—

Mr. W. H. BAMFORD, for his Paper on "Cupola Practice with a view to Closer Carbon Control," given before the Birmingham Branch.

Mr. W. MACHIN, for a joint Paper on "Castings," given by himself and Mr. M. C. OLDHAM, to the Lancashire Branch.

Mr. P. A. RUSSELL, for his Paper on "Some Experiences in the Manufacture of High-Grade and High-Duty Alloy Iron Castings," given before a joint meeting of the London and East Midlands Branches.

Mr. J. ROXBURGH, for his Paper on "The Technique of Chilling," given before the Sheffield Branch.

Mr. T. TYRIE, for his Paper on "Defects in Iron Castings: Their Cause and Cure," given before the Scottish Branch.

Mr. T. R. WALKER, for his Paper on "The Testing of Steelfoundry Sands and the Control of Supplies by Specification," given before the Sheffield Branch.

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The Institute of British Foundrymen

THIRTY-SECOND ANNUAL CONFERENCE, SHEFFIELD

JULY 2, 3, 4 and 5, 1935

The Thirty-second Annual Conference was held at Sheffield on July 2, 3, 4 and 5, 1935, under the Presidency of Mr. J. E. Hurst. The arrangements for the Conference were made by the Sheffield Branch, with Mr. T. R. Walker, secretary of the Branch, as Secretary of the Conference Committee.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Institute was held in the Mappin Hall, St. George's Square, on Tuesday, July 2, with the retiring President, Mr. Roy Stubbs, in the chair.

The minutes of the preceding annual general meeting were taken as read, and were confirmed and signed.

The Annual Report of the Council for the session 1934-35 was presented.

ANNUAL REPORT

This report covers the twelve months ended April 30, 1935, and the accounts are for the year ended December 31, 1934.

Membership

An examination of the membership figures shows that 181 new members were added during

the year, while, on the other hand, the names of 233 members were removed from the roll, showing a net loss of 52. This reduction is partly due to the trade conditions which prevailed during the years 1931 and 1932, which are usually reflected in the membership of this Institute a few years afterwards, but the principal cause of the reduction in figures is due to the very drastic revision of the register which has taken place. The great majority of the present membership of 1,780 can be considered as really active members who maintain their interest and continue their subscriptions. This assumption is borne out by an examination of the financial statement, which shows that in spite of reduction in membership, there has been practically no reduction in the income from subscriptions.

Table I shows the changes in membership, and an analysis of the present membership is given in Table II.

TABLE I.—*Changes of Membership.*

	Subscribing firms.	Members.	Associate members.	Associates.	Total.
At April 30, 1934..	50	744	934	104	1,832
Additions and transfers from other grades ..	3	63	95	20	181
	53	807	1,029	124	2,013
Losses and transfers to other grades	4	78	128	23	233
At April 30, 1935	49	729	901	101	1,780

Honorary Members

Sir Wm. J. Larke, K.B.E., and Mr. S. G. Smith, have been elected Honorary Members for their services to the industry and to the Institute in particular.

TABLE II.—*Analysis of Membership, April* 30, 1935.

Branch.	Subscribing Firms.		Members.		Associate Members.		Associates.		Total.	
Birmingham	3	(2)	108	(106)	117	(114)	14	(17)	242	(239)
East Midlands	3	(3)	44	(46)	85	(79)	3	(3)	135	(131)
Lancashire	15	(15)	119	(121)	228	(240)	27	(24)	389	(400)
London	5	(6)	147	(147)	73	(80)	8	(7)	233	(240)
Middlesbrough			21	(25)	38	(38)	7	(5)	66	(68)
Newcastle	6	(6)	28	(35)	26	(36)	21	(29)	81	(106)
Scottish	5	(6)	86	(87)	180	(173)	11	(10)	282	(276)
Sheffield	6	(6)	81	(84)	60	(70)	5	(7)	152	(167)
Wales and Monmouth ..	2	(2)	30	(26)	28	(33)	3		63	(61)
West Riding of Yorkshire	3	(3)	38	(35)	62	(60)	1	(1)	104	(99)
Unattached	1	(1)	27	(32)	4	(11)	1	(1)	33	(45)
	49	(50)	729	(744)	901	(934)	101	(104)	1,780	(1.832)

The three Associates attached to the Wales and Monmouth Branch are Student Associates.

Honours Conferred upon Members

Among the honours which have been conferred upon members of the Institute, are the following:—

The Rt. Hon. Arthur Henderson, M.P., has been awarded the Nobel Peace Prize.

Dr. W. H. Hatfield has been elected a Fellow of the Royal Society, and also Vice-President of the Iron and Steel Institute.

Sir H. C. H. Carpenter has been elected President of the Iron and Steel Institute.

Sir Wm. J. Larke, K.B.E., has been elected Vice-President of the Iron and Steel Institute

Mr. H. Winterton, Junior Vice-President, has been appointed a Bailie of the Burgh of Milngavie.

Deaths

It is with regret that the Council reports the deaths of ten members.

Finance

The Balance Sheet and Income and Expenditure Account, are given on pages 12 to 15. It will be noted that there was an excess of income over expenditure of £208 14s. 5d., which is the largest credit balance to be reported for some years. This is due to economical working in all directions, particularly on the part of the Branches, to whom thanks are due for the reduction in their expenditure which has been achieved without diminishing their efficiency. The cash at the bank, £509 4s., includes a sum of £69 4s. 11d., which has been transferred from the surplus funds in the hands of the Branches.

Although the finances are in a very satisfactory condition, the Council is conscious of the importance of closely scrutinising every item of expenditure, and a Special Sub-Committee is at present reviewing every aspect of this matter

Technical Committee

The Technical Committee and its Sub-Committees continue to carry out valuable work in reviewing technical developments in every

branch of the industry. The detailed report of the work of the Technical Committee is given on pages 17 to 26.

Manchester Conference

The Thirty-first Annual Conference was held in Manchester, from June 5 to 8, 1934. The Lord Mayor of Manchester opened the Conference on Wednesday, June 6, and with the Lady Mayoress was present at the Annual Banquet on the evening of the same day.

At the Opening Meeting of the Conference Mr. Roy Stubbs was installed President in succession to Mr. C. E. Williams.

The Council tenders its sincere thanks to the Lord Mayor of Manchester and the Lady Mayoress, and to all those firms who arranged visits for members and ladies to their works; to the staffs of those firms; to the authors of Papers; to those who subscribed to the funds and to all who assisted in any way in the organisation of this very successful Conference.

The thanks and congratulations of the Council are specially tendered to the members and ladies of the Lancashire Branch who were responsible for the organisation, and particularly to the Branch President, Mr. W. N. Cook; to the Chairman of the Conference Committee, Mr. A. Phillips; to Mr. J. E. Cooke, the Conference Secretary, and Mrs. J. E. Cooke, Secretary of the Ladies' Committee.

Presentation of Badges

At the Manchester Conference, the members of the Lancashire Branch presented to the Institute, a gold badge of office for the use of the President, at official functions, and the ladies of the Lancashire Branch presented a similar badge for the use of the President's wife. Mr. and Mrs. C. E. Williams also presented an official badge for the use of the Vice-President. The Council tenders its grateful thanks for these valuable gifts.

Mr. C. E. Williams

The Council wishes to acknowledge its indebtedness to Mr. C. E. Williams whose term

of office as President terminated at the Manchester Conference, and also to Mrs. Williams. The Council has decided to commemorate Mr. Williams' year of office by establishing the Edward Williams Lecture, which will be given annually at future Conferences. The first lecture will be delivered at Sheffield on Wednesday, July 3, 1935, by Sir Wm. J. Larke, K.B.E.

Mr. Williams' own Branch, the Wales and Monmouth Branch, also showed their appreciation of his services and those of Mrs. Williams, by entertaining them to a complimentary Dinner in December last.

Other Technical Organisations

The Institute has maintained and strengthened its relations with other technical organisations. It is now represented through its Technical Committee, on most of the important B.S.I. Committees which are of interest to the foundry trade, and keeps in close contact with other technical bodies in the engineering industry.

Along with other similar organisations, the Institute co-operated with the Iron and Steel Institute in the Symposium on Welding, which was held in London recently.

British Cast Iron Research Association

The Annual Report of the British Cast Iron Research Association for the year ending June, 1934, showed that the income was the highest ever recorded in its history, the drop in Government grant which took place in 1932 as a consequence of the depression having been more than made good from industrial sources, H.M. Government has offered for the current year to increase the grant by £2,000 provided an additional £1,000 is secured from industry, and the support of eligible non-members is invited to enable this to be achieved. The Government offer also provides for further increase in grant as the industrial income increases in a way which makes it possible to reach before 1940 a total income of £20,000 per annum. In line with this expansion, the Research Programme

has been enlarged, the staff increased and work which should be of the highest interest and importance to the industry is progressing.

Invitations

Messrs. F. W. Bridges & Sons, Limited, have invited the Council to luncheon, and the whole of the members to tea at the Shipping, Engineering and Machinery Exhibition to be held at Olympia in September. They have also placed at the disposal of the Institute, a stand in the Foundry Section of the Exhibition. The Technical Committee has undertaken the responsibility of utilising this stand to show recent progress in foundry practice, and to indicate the share which the Institute has taken in that progress. The Birmingham Chamber of Commerce has also invited the members of the Council to luncheon at the British Industries Fair at Birmingham, on May 29.

Overseas Foundry Associations

Ten members and ladies attended the International Foundry Conference which was held in Philadelphia in October, and took part in a pre-Conference tour of some of the principal cities in the United States. During this tour they were enabled, by the courtesy of our American friends, to visit some of the most important foundry plants in America, and make contact with a large number of important American foundrymen.

A meeting of the International Committee of Foundry Technical Associations was held in Philadelphia during the Conference, and was attended by Mr. James Smith and Mr. T. Makemson, as representatives of the Institute, and also by Mr. V. Delport in his capacity as European representative of the American Foundrymen's Association.

An International Foundry Conference will be held in Brussels from September 20 to 25. Arrangements are now being made to organise a party of members and ladies to attend this Conference, in response to an invitation received from the Belgian Foundrymen's Association.

The author of the official Exchange Paper to the International Conference in Philadelphia was Dr. W. H. Hatfield. Mr. E. Longden was the author of the Exchange Paper given to the French Foundry Conference at Nancy in July. Exchange Papers will be presented on behalf of the Institute at forthcoming Conferences as follow:—American Foundrymen's Association, Toronto—Mr. A. J. Murphy; International Foundry Conference, Brussels—Mr. H. H. Beeny; French Foundry Conference, Paris—Mr. P. A. Russell. At our own Conference, to be held in Sheffield in July next, Papers will be presented on behalf of the American, French and German Foundry Technical Associations.

Branch Activities

Perhaps the most important of the Institute's activities centre round the Branches. During the year under review, meetings have been held regularly in about twenty cities and towns; nearly 100 Papers have been presented at Branch meetings in addition to several general discussions and the Branch-Presidents' addresses.

The Institute is deeply indebted to the Branch officials for their devoted work, and also to the authors of Branch Papers, and firms with whom they are associated. In November last, an important new departure took place in London in the form of a two-days' joint meeting with the London and East Midlands Branches.

Educational Activities

The Degree Course in Founding at the University of Sheffield, to which reference has been made in previous reports, was established in the autumn of 1934 and is now in operation. The Institute has been responsible for much of the preliminary work in connection with the establishment of the Course, and through our instrumentality a number of firms have pledged themselves to support the scheme financially for a period of seven years. A number of donations have also been given, and the members of the Institute have themselves subscribed the sum of

£50 13s. as a donation towards the expenses of the Course.

Much progress has already been made in connection with the establishment of the intensive course in Foundry Practice designed for persons already engaged in the foundry industry, which is to be established at the Birmingham Central Technical College under the auspices of the British Cast Iron Research Association.

The examinations in Foundry Practice and in Patternmaking conducted by the City and Guilds of London Institute, are being held as this report is being prepared. The results are not yet available; the following figures, however, show the results of the 1934 examinations.

	No. of candidates.	Pass 1st class.	Pass 2nd class.	Percentage of passes.
Patternmaking— Intermediate grade	26	5	10	57.7
Patternmaking— Final grade ..	19	5	9	73.7
Foundry Practice and Science ..	45	9	20	64.4

Prizes were awarded as follow:—PATTERNMAKING, Intermediate Grade—Mr. G. V. Dipple, of Coventry, Bronze Medal; PATTERNMAKING, Final Grade—Mr. W. G. Humpheson, of Wolverhampton, Silver Medal and Buchanan Prize of the Institute of British Foundrymen, Mr. S. A. Horton, Derby, Buchanan Silver Medal of the Institute of British Foundrymen, and Mr. J. S. Ferguson, Glasgow, Buchanan Prize; FOUNDRY PRACTICE AND SCIENCE—Mr. L. G. Boulton, of Wednesbury, Bronze Medal and Buchanan Prize of the Institute of British Foundrymen, and Mr. W. Brindley, Wolverhampton, Buchanan Prize.

National Certificates

Thirty-two National Certificates in Mechanical Engineering with special reference to foundry work, were endorsed by the President of the Institute, making a total of 103 since the commencement of the endorsement of these certificates which are issued jointly by the Institution

of Mechanical Engineers and the Board of Education.

In the autumn of 1934, the new Trade School was opened by the Education Committee of the City of Glasgow. The Scottish Branch of the Institute has been largely responsible for the organisation of the foundry and patternmaking sections of this school. Mr. A. Campion, Past-President of the Branch, has rendered important work in this connection, and the classes in these subjects are under the general control of Mr. J. Longden, Past-President of the Branch.

Awards

The following awards were made by the Institute during the year:—

The Oliver Stubbs Medal. The thirteenth award was made in June, 1934, to Mr. V. C. Faulkner, Past-President, "for his work in connection with the establishment of the Degree Course in Founding at the University of Sheffield."

Meritorious Services Medal. The second award of this medal was made in June, 1934, to Mr. J. J. McClelland, honorary secretary of the Wales and Monmouth Branch since its establishment, "as a recognition of his devoted service for many years."

Diplomas. The announcement of the award of Diplomas for the year 1934 was made at the Manchester Conference. The names of the recipients and the Branches before which the Papers were given, are as follow:—

W. G. Morgan, Birmingham Branch.
F. Hudson, Lancashire and London Branches.
A. Logan, Lancashire Branch.
T. Makemson, London Branch.
G. L. Bailey, London Branch.
Dr. A. B. Everest, London Branch.
J. Longden, Scottish Branch.
J. Roxburgh, Sheffield Branch.
B. Gale, Wales and Monmouth Branch.

Surtees Memorial Examination. The 1935 examination was held by the Newcastle Branch.

All the candidates entered in the Junior Section of the examination, and the results were of a very high standard.

Prizes were awarded as follow:—

Silver Medal, H. Vasey.
2nd Prize, J. Slater.
3rd Prize, F. W. Latimer.

In view of the very high standard, consolation prizes were also awarded to other candidates. The Governors of the Examination wish to acknowledge their indebtedness to the authorities of the Rutherford Technical College, Newcastle, for the excellent arrangements they made in connection with the examination.

Employment Bureau

The Employment Bureau continues to assist in making contact between employers and members who are in search of positions. The Institute continues to be indebted to the proprietors of the "Foundry Trade Journal" for the facilities which they have afforded. It is satisfactory to note that due to the improved trade conditions, a much smaller number of members are disengaged.

Bye-Laws and Rules

The certificate of His Majesty's Privy Council in respect of the revised Bye-Laws was given in October last. Copies of the Bye-Laws and Branch Rules which are now in operation have been circulated to all members.

Council

Four Council meetings and a large number of Committee meetings have been held at Manchester, Blackpool, Bradford and Glasgow. The average attendance was 40. There have also been several meetings of various special sub-committees. There have been eight meetings of the Technical Committee and Technical Council, and, additionally, over forty sub-committee meetings have been held. Of the ten members of the Council elected by ballot, five retire each year. The five who so retire at the annual

general meeting on July 2 are:—Prof. J. H. Andrew, Messrs. V. Delport, J. R. Hyde, E. Longden and D. H. Wood. All these gentlemen offer themselves for re-election.

The Council again wishes to tender its thanks to Mr. W. B. Lake, J.P., honorary treasurer, for his valuable work in connection with the Institute's finances, the results of which are reflected in the improved financial position.

Sheffield Conference

The Thirty-second Annual Conference will be held at Sheffield from July 2 to 5, when Mr. J. E. Hurst, President-Elect, will be installed President of the Institute.

ROY STUBBS,
President.

TOM MAKEMSON,
Secretary.

BALANCE SHEET, DECEMBER 31, 1934.

LIABILITIES.

	£ s. d.	£ s. d.
Subscriptions paid in advance		123 18 0
Sundry Creditors		437 17 10
The Oliver Stubbs Medal Fund:—		
Balance from last Account	210 14 6	
Interest to date	7 16 7	
Income Tax Refund ..	2 11 4	
	221 2 5	
Less Cost of Medal ..	9 9 0	
		211 13 5
The Buchanan Medal Fund:—		
Balance from last Account	125 13 1	
Interest to date	4 14 9	
	130 7 10	
Less Cost of Medal and Prizes	7 15 7	
		122 12 3
Sheffield University Fund ..		46 9 0
International Conference Fund:—		
Surplus included in General Investments		40 18 11

	£ s. d.	£ s. d.
Accumulated Fund :—		
Balance at December 31, 1933	1,488 17 11	
Add : Excess of Income over Expenditure for the year ended December 31, 1934	208 14 5	
		1,697 12 4
		£2,681 1 9

ASSETS.

	£ s. d.	£ s. d.
Cash in hand of Secretaries :—		
Lancashire	18 5 4	
Birmingham	31 16 6	
Scottish	15 18 5	
Sheffield	24 8 6	
London	54 3 5	
East Midlands	24 9 0	
West Riding of Yorkshire	15 4 9	
Wales and Monmouth ..	0 12 3	
Middlesbrough	8 14 6	
		193 12 8
General Secretary		9 17 6
Sundry Debtors :—		
Subscriptions due and subsequently received ..		122 17 0
Lloyds Bank Ltd.		509 4 0
Do. (Sheffield University Fund)		46 9 0
The Oliver Stubbs Medal Fund :—		
£342 5s. 7d. Local Loans £3 per cent. Stock at Cost	200 0 0	
Balance at Lloyds Bank Ltd.	11 13 5	
		211 13 5
The Buchanan Medal Fund :—		
£125, £3 10s. 0d. per cent. Conversion Stock at 78¼	98 6 9	
Balance at Midland Bank	24 5 6	
		122 12 3
Investments Account :—		
£650 3½ per cent. War Loan at Cost	630 8 4	
£300 5 per cent. Conversion Stock, 1944-64, at Cost	297 14 11	
£653 19s. 0d. Local Loans 3 per cent. Stock at Cost	451 13 8	
		1,379 16 11

	£ s. d.	£ s. d.
Furniture, Fittings, and Fixtures :—		
Per last Account	94 7 10	
Less : Depreciation 10 per cent.	9 8 10	
		84 19 0
		£2,681 1 9

W. B. Lake, *Hon. Treasurer.*
Tom Makemson, *Secretary.*

We have prepared and audited the above Balance Sheet with the Books and Vouchers of the Institute, and certify the same to be in accordance therewith.

J. & A. W. Sully & Co., *Chartered Accountants, Auditors.*

19–21, Queen Victoria Street, London, E.C.4.
March 21, 1935.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED DECEMBER 31, 1934.

Expenditure.

	£ s. d.	£ s. d.
Postages		107 18 9
Printing and Stationery, including printing of "Proceedings"		606 15 9
Council, Finance and Annual Meetings Expenses ..		80 19 4
Medal for Past President ..		3 0 0
Branch Expenses :—		
Lancashire	121 16 1	
Birmingham	68 3 6	
Scottish	88 6 7	
Sheffield	64 14 0	
London	45 10 5	
East Midlands	38 14 3	
Newcastle	37 2 1	
West Riding of Yorkshire	27 10 3	
Wales and Monmouth ..	29 1 6	
Middlesbrough	23 14 6	
		544 13 2
Audit Fee and Accountancy Charges ..		12 12 0
Incidental Expenses		60 6 8
Salaries—Secretary and Clerks		665 18 5
Rent, Rates, &c., of Office, *less* Received		90 4 4

	£	s.	d.
Branch Expenses (*continued*) :—			
Subscription International Committee ..	5	0	0
Depreciation of Furniture	9	8	10
John Surtees Memorial Examinations Grants to Branches	8	2	5
	2,194	19	8
Excess of Income over Expenditure carried to Balance Sheet	208	14	5
	£2,403	14	1

INCOME.

	£	s.	d.	£	s.	d.
Subscriptions received :—						
Lancashire				456	12	0
Birmingham				333	18	0
Scottish				360	18	6
Sheffield				225	15	0
London				374	18	10
East Midlands				151	14	6
Newcastle				86	2	0
West Riding of Yorkshire				124	8	6
Wales and Monmouth ..				87	3	0
Middlesbrough				86	12	6
Unattached Members ..				42	16	0
				2,330	18	10
Add : Subscriptions in Advance, 1933	97	2	6			
Do. due 1934 ..	122	17	0			
				219	19	6
				2,550	18	4
Less : Subscriptions in Advance, 1934	123	18	0			
Do. due 1933 ..	99	4	6			
				223	2	6
				2,327	15	10
Sale of " Proceedings," &c.				10	19	6
Interest on Investments and Cash on Deposit				51	16	1
Income Tax Refund ..				8	13	0
John Surtees Medal Fund, Surplus				3	2	6
Profit on Sale of Badges ..				1	7	2
				£2,403	14	1

The resolution for the adoption of the Report was proposed by the retiring PRESIDENT, who commented on the satisfactory progress which it reflected, and was seconded by MR. A. HARLEY (Past-President), who was also gratified by the fact that it showed considerable activity in all branches of the Institute's work. The Institute, he said, was in a flourishing condition, and the members had every reason to be satisfied.

The Report was adopted.

Finance

MR. W. B. LAKE, J.P. (hon. treasurer), proposing the adoption of the accounts, called attention to the fact that there was an excess of income over expenditure of more than £200. That result had been attained by economical working on the part of the Branches and close co-operation between the Branches and the General Council. He tendered his sincere thanks to the Branches for that co-operation. The General Council had decided, he added, to invest £300 in Government securities from the balance in hand; this was made possible by adopting the policy of not keeping balances in the hands of the Branches, but of transferring their surpluses to the General Fund.

MR. A. SUTCLIFFE suggested that the Branches were holding too much money.

MR. T. MAKEMSON (Secretary) replied that the amounts of cash in the hands of the Branches, as shown in the accounts, were the amounts in hand on December 31, 1934. Those sums—less about £10 in each case—had since been paid into the General Fund, in accordance with the policy which had been adopted during the last four or five years—he believed since Mr. Sutcliffe himself had made the suggestion. The rule was that before the end of March of each year the Branches returned to General Fund the amounts they had in hand, less a working balance of £10.

The motion for the adoption of the balance sheet and accounts was carried.

Report of Technical Committee

Mr. J. W. Gardom (Convener of the Technical Committee) moved the adoption of the Committee's fourth Annual General Report. He expressed his personal appreciation of the help afforded him by the officers of the sub-committees and the members of the Technical Committee as a whole, who had devoted much time and work, and had gone to considerable expense in carrying on the work.

During the past year the Committee had achieved one thing which he had always hoped it would achieve, *i.e.*, closer co-operation with outside bodies, such as the British Standards Institution. In the past the Institute of British Foundrymen had been very well represented on the B.S.I.; but he had felt that there was no organisation by which they could keep in close touch with the feeling of the members of the Institute generally, except by writing or by personal contact. Nowadays, however, they could obtain through the Technical Committee an idea of what the Institute, as a whole, wanted to be done on the technical side.

Mr. Victor Stobie (Past-President), seconding the resolution for the adoption of the Technical Committee's Report, said the amount of work done was evidenced by the fact that more than 50 meetings had been held during the year, and the members of the Committee were making a really valuable contribution to the advancement of the industry.

The Report was adopted.

FOURTH ANNUAL GENERAL REPORT OF THE TECHNICAL COMMITTEE

Since the publication of the last Annual Report, four meetings of the Technical Committee have been held at Carlisle (twice), Birmingham and London. Four meetings of the Technical Council have also been held at Manchester, Blackpool, Bradford and Glasgow. Meetings of all sub-committees have been held on the same dates as the meetings of the Technical Committee and numerous additional sub-committee meetings have been held also. The

total number of meetings of the Technical Committee, Technical Council and sub-committees during the last twelve months is about fifty.

The Technical Council consists of members elected by the Branches and certain *ex-officio* members; the Technical Committee consists of the Technical Council with the addition of a number of members who are co-opted on various sub-committees by reason of their special knowledge and experience. These bodies form the necessary liaison between and give the necessary direction to the various sub-committees through which the bulk of the work is carried out. As will be seen from the attached detailed reports, the activities of these sub-committees cover almost every branch of foundry practice.

Sub-Committee Reports

In addition to their normal activities of investigation and correlation, sub-committees from time to time issue reports dealing with certain phases of their work. An exhaustive report by the Cast Iron Sub-Committee was presented to the Manchester Conference, and aroused considerable interest and discussion. During the winter session, this report was re-read at four Branches, on each occasion by a member of the Cast Iron Sub-Committee, and the committee is now engaged in classifying the various suggestions and criticisms made in the discussions before the branches, with a view to incorporating them in their future work.

An interim report on melting costs has been prepared by the Costing Sub-Committee with a view to stimulating discussion and criticism. This report was presented at six Branches during the winter. Very valuable suggestions were received during the ensuing discussions and these suggestions are being utilised by the committee. The practice of presenting such reports to the various Branches adds considerably to the labours of the sub-committees and of the members who present the report in various parts of the country, but the practice does bring the report

to the individual notice of a large body of members of the Institute and enables the sub-committees concerned to avail themselves of a considerable volume of suggestions and criticism.

A report on tolerances of dimensions of malleable castings has been prepared by the Malleable Iron Sub-Committee, but has not yet been published. This report has opened up a very wide field, inasmuch as the subject is of importance in other branches of foundry practice in addition to malleable iron founding. The report is now being extended, in consultation with other sub-committees, so that eventually it will be a comprehensive report on the subject dealing with all types of castings.

General Activities

Apart from the work of the sub-committees, the Technical Committee, as a whole, is active in several directions which will ultimately be of benefit to members of the Institute, such general activities include representation of the Institute on committees of the British Standards Institution and other similar bodies. The Technical Committee is now the Institute's recognised medium for keeping in contact with such organisations, and by means of its representatives the Institute is in direct and continuous contact with the preparation and revision of specifications and other similar matters. Mr. P. A. Russell, Convener of the Cast Iron Sub-Committee, has been elected chairman of the B.S.I. Sub-Committee, M.E./35/2, Grey-Iron Castings.

Attention has been given to the question of investigating a suitable test for relative fluidity or "castability" of cast iron, steel and non-ferrous metals. Individual members of the committee have carried out exhaustive tests on various types of apparatus with a view to making recommendations in the near future.

Most investigators of foundry practice sooner or later find difficulty in the fact that many foundry terms have a purely local significance. Realising that some kind of standardisation of foundry terms is desirable, at least in their own work, the Committee is now endeavouring to

collect lists of terms which vary in various parts of the country, with a view to recommending standard practice.

Foundry Exhibition

It will be remembered that at the International Foundry Exhibition held in London in April, 1933, the Technical Committee was enabled, through the courtesy of the organisers, to arrange a very successful technical exhibit. Another exhibition will be held in September next, at Olympia, in association with the Shipping, Engineering and Machinery Exhibition, and Messrs. F. W. Bridges & Sons, Limited, have kindly placed a stand at the disposal of the Institute for a similar exhibit. The Technical Committee has undertaken to be responsible for organising this exhibit.

The Inquiry Bureau, which was instituted in October, 1932, continues to perform useful service to members of the Institute. A large number of small inquiries have been dealt with, whilst a number of major inquiries have been answered, involving considerable preparation on the part of the various sub-committees and of individual members of those committees.

Members of the Institute are invited to avail themselves of the services of the Inquiry Bureau in connection with problems which they may encounter, or information which they may require. Correspondence should be addressed to the Secretary of the Institute.

On behalf of the Institute as a whole, the Convener wishes to acknowledge the valuable work which is done by the conveners of the sub-committees and by the individual members, and also the facilities which are granted by the firms with which the members of the committees are connected. Without such loyal and generous support the success of the Committee's work would be impossible. Members frequently travel long distances to attend meetings at their own expense, and on behalf of the Institute the Convener tenders his thanks to them and to all who have co-operated with them.

The Convener also wishes to express the Institute's thanks to the large number of firms who have co-operated with the Melting Furnaces Sub-Committee on the questionnaire on cupola linings and patching materials, and with the Costing Sub-Committee in connection with their work, and the firms who are co-operating with the Sands and Refractories Sub-Committee in supplying information and carrying out tests.

J. W. Gardom,
Convener,
Technical Committee.

REPORTS OF SUB-COMMITTEES

Sub-Committee on Costing

Since the last Annual Report, the Costing Sub-Committee has held five meetings, at Luton, London, Leicester and Derby. A substantial amount of work has also been effected by correspondence.

A preliminary Paper on "Costs in the Melting Department of a Grey-Iron Foundry" was presented before the following Branches and Sections:—Birmingham, Derby, London, Glasgow, Sheffield, Lincoln. The Paper was also published in the "Foundry Trade Journal" (November 8, 1934). The discussions that followed the presentation of this Paper were most helpful, and, as a result, the Sub-Committee was enabled to draft definite recommendations relative to melting costs. These recommendations have not yet been published. The question of production costs in the moulding department is under consideration, and our investigations on that point are practically completed.

It is hoped that recommendations relative to costs in the core-making department and in the cleaning and finishing department will be ready before the end of the year. It is our intention to prepare a preliminary report on the whole subject of "Costs in a Grey-Iron Foundry," and it is suggested that this report be available for presentation before the various Branches during the present year. This preliminary

report would also be available for the Glasgow Conference in 1936. It is hoped that the report may be published in due course in the "Foundry Trade Journal."

Endeavours will be made to present the work of the Sub-Committee, in a condensed form, at the Foundry Exhibition, on the stand of the Technical Committee, next September. It is of interest to note that the discussions which followed the publication of the Paper on melting costs were of great assistance to the Sub-Committee, and it is hoped that similar discussions on production costs will take place. Since the last Annual Report, the Costing Sub-Committee has co-opted Mr. C. C. Booth, who has given valuable assistance from the standpoint of the jobbing foundry.

V. Delport,
Convener.

Sub-Committee on Melting Furnaces

The Sub-Committee has proceeded with the questionnaire on cupola-lining and patching materials, mentioned in the last report, and details of some 50 cupolas are now available. The results of this inquiry have been tabulated, and the data will be made available very shortly. The Sub-Committee hopes to present a symposium of foundry melting furnaces at the next annual conference, with a view to providing data on modern melting practice. A start has been made on the collection of practical operating data for non-ferrous furnaces.

F. K. Neath,
Convener.

Sub-Committee on Sands and Refractories

A year ago the Sub-Committee decided to issue a questionnaire on moulding-sand mixtures, for distribution to various foundries, hoping thereby to arouse an interest in sand testing, and enable the Committee to make practical tests on a number of different sand

mixtures, also to enable the Sub-Committee to check the results on the sand-testing apparatus they have recommended. The work of issuing this questionnaire and dealing with the replies and samples sent in, has formed the bulk of the work carried out this session. Copies have been sent to all the Branches for distribution, with the following results up to date:—

Birmingham. Representatives: Messrs. A. Tipper, J. J. Sheehan, Dr. Skerl. Replies received, 5; tests completed, 4.

Lancashire, Sheffield, East Midlands, West Riding of Yorkshire. Representative: Mr. T. R. Walker. Replies received, 1; tests completed, 1.

Middlesbrough, Newcastle. Representatives: Messrs. N. D. Ridsdale and A. Logan. Replies received, 8; tests completed 4.

Scottish, Falkirk, Edinburgh. Representatives: Messrs. F. Hudson, A. Campion, W. Y. Buchanan. Replies received, 3; tests completed, 3.

London. Representative: Mr. H. H. Shepherd. Replies received, 4; tests completed, 4.

Wales and Monmouth. Representatives: Messrs. R. J. Richardson and B. Hird. Replies received, 1; tests completed, 1.

Total replies received, 22; total tests completed, 17.

The dry compression-strength testing apparatus designed by Mr. W. Y. Buchanan has been developed and tried out during the session, in co-operation with Mr. F. Hudson and other members of the Sub-Committee. They have obtained very satisfactory results and the Sub-Committee is now engaged in drawing up a specification for size of test-piece and time and temperature for drying. This type of apparatus has been accepted as standard for the time being by the Sub-Committee.

Fluidity tests with the spiral test-piece have been discussed, and tests carried out and reported on by our members.

BEN HIRD,
Convener.

Sub-Committee on Cast Iron

Since the presentation of the report to the Manchester Conference, this report has been re-discussed at meetings of four Branches, a member of the Sub-Committee summarising the report and replying to the discussion. The question of the soundness of castings is still before the Sub-Committee, but little further experimental work has yet been carried out.

The Sub-Committee has been principally concerned with the proposals for a higher specification for grey cast iron, and has made recommendations to the British Standards Institution for three grades of high-duty cast iron to be incorporated in a new specification. These recommendations have been accepted by the British Standards Institution as a basis for discussion, and this Sub-Committee is now actively engaged in the preparation of the necessary data for the tests. The question of bar sizes is also up for discussion by the British Standards Institution, and this Sub-Committee is considering its recommendations on this subject. In connection with the work on the B.S.I. Specifications, the Sub-Committee has obtained the co-operation of six additional members who are particularly equipped to deal with this matter, and is also working in close co-operation with the British Cast Iron Research Association.

The Sub-Committee has in the course of preparation a second series of typical microstructures illustrating various forms of cast iron not included in the first series; it is hoped that this will be available to members during the autumn of this year. The work on carbon pick-up has been held up owing to the pressure of other work upon the Sub-Committee. The Sub-Committee has co-operated with the Technical Committee and its Sub-Committees in various ways.

P. A. Russell,

Convener.

Sub-Committee on Malleable Cast Iron

An investigation of the possibility of utilising a standard-sized bar, but specifying different test requirements to satisfy various sections of metal was carried out. The work has been brought to a conclusion so far as black-heart malleable cast iron is concerned, but it has been considered that additional tests should be made upon white-heart malleable so that this work is still in progress. Work on the correlation of the physical properties of malleable cast iron with micro-structures has been continued, but is still far from being completed.

The Sub-Committee has completed an investigation of the accuracy of castings to drawings and patterns obtained in normal practice, and has produced data illustrating the effect of many variable factors in moulding and casting. A report was presented to the Technical Committee and the matter has now been referred back to the Malleable Sub-Committee for the inclusion of additional data which are being supplied by the Sub-Committees on steel, non-ferrous and grey iron.

During the year the British Standards Institution has considered the revision of the malleable specifications and our Technical Committee has been represented on the appropriate B.S.I. Committee. The Malleable Sub-Committee from its past work has definite recommendations to put before the B.S.I. Some additional work is planned which, it is hoped, will result in useful guidance to the B.S.I. Committee in its work.

A. E. Peace,
Convener.

Sub-Committee on Non-Ferrous Castings

This Sub-Committee now comprises ten members, both elected and co-opted, whose work in the past year has been most helpful. Since the third report, issued last year, attendances have been made at four sub-committee and four full

Technical Committee meetings held in Manchester, London, Birmingham and Carlisle. The chief work undertaken has been the consideration and correlation of the tests obtained from various sources on the two leaded gun-metals and three leaded phosphor bronzes intended for recommendation to the British Standards Institution. Minor adjustments in the proposed composition ranges have been made and check tests instituted, but full agreement has not yet been reached in regard to the nature and values of the physical tests to be put forward. Further meetings and discussions are in progress.

J. S. G. Primrose,
Convener.

Sub-Committee on Steel Castings

The Steel Sub-Committee has further investigated the valve casting, only two of which have to be completed. We have fortunately arranged for the testing of these castings to be conducted by a valve user, and hope to obtain a fair comparative report. Izod impact values are being investigated and are being discussed. We were able to assist the malleable general committee with particulars on tolerances on steel castings, and we are drafting out further details in this connection. During the coming Session we hope to complete our report on our findings in the valve investigation.

R. J. Richardson,
Convener.

Oliver Stubbs Gold Medal

The Retiring President reported that the Council had decided not to make an award of the Oliver Stubbs Medal this year.

Meritorious Service Medal

It was announced that a Meritorious Service Medal had been awarded to Mr. H. Bunting (who is retiring shortly from the office of hon. secretary of the East Midlands Branch).

Diplomas

It was announced that the Council had awarded Diplomas, as follows, for Papers presented to the Branches during the past session:

Mr. W. H. Bamford, for a Paper on "Cupola Practice, with a view to Closer Carbon Control," read before the Birmingham Branch.

Mr. P. A. Russell, for a Paper on "Some Experiences in the Manufacture of High-Grade and High-Duty Alloy Iron Castings," read at a joint meeting of the London and East Midland Branches.

Mr. W. Machin, for a Paper on "Castings." The Paper was presented jointly by Mr. Machin and Mr. M. C. Oldham, but Mr. Oldham was not at that time a member of the Institute and the diploma is awarded to Mr. Machin.

Mr. T. Tyrie, for a Paper on "Defects in Iron Castings—their Cause and Cure," read before the Scottish Branch.

Mr. T. R. Walker, for a Paper on "The Testing of Steel-foundry Sands and the Control of Supplies by Specification," read before the Sheffield Branch.

Mr. J. Roxburgh, for a Paper on "The Technique of Chilling," read before the Sheffield Branch.

Election of President

The election of Mr. J. E. Hurst as the new President of the Institute was proposed by the retiring PRESIDENT and seconded by MR. C. E. WILLIAMS (Past-President). References were made to his international reputation as a metallurgist. Mr. Hurst was unanimously elected.

Vote of Thanks to Retiring President

A hearty vote of thanks was accorded Mr. Stubbs for his services to the Institute as President, and the hope was expressed that he would continue to give the Institute the benefit of his services in the future as in the past. Mrs. Stubbs was also thanked for her great assistance during the past year.

Election of Vice-Presidents

Mr. H. Winterton (Scottish Branch) was elected Senior Vice-President and Mr. C. W. Bigg (East Midlands Branch) was elected Junior Vice-President.

Auditors

Messrs. J. & A. W. Sully & Company (chartered accountants) were unanimously re-elected auditors for the coming year.

Members of Council

On Wednesday morning the result of the ballot for the election of members of Council was announced. The following were elected:—Elected for two years—Prof. J. H. Andrew; Mr. V. Delport; Mr. E. Longden; Mr. P. A. Russell; Mr. D. H. Wood. Elected for one year—Mr. R. A. Miles. (Mr. Miles was elected in succession to Mr. E. Stevenson, who has resigned.)

Reception at the Town Hall

At a reception held in the evening at the Town Hall, Sheffield, the guests were received by the Lord Mayor and Lady Mayoress (Alderman and Mrs. P. J. M. Turner) and by the President of the Institute (Mr. Roy Stubbs) and Mrs. Stubbs.

WEDNESDAY, July 3

The first session of the Conference proper opened on Wednesday morning, July 3, in the Mappin Hall of the University, St. George's Square. The retiring President (Mr. Roy Stubbs) presided during the early part of the proceedings.

Civic Reception

The Lord Mayor of Sheffield (Alderman P. J. M. Turner), the Master Cutler (Mr. A. Williamson), the President of the Sheffield Chamber of Commerce (Mr. A. K. Wilson) and other representatives of the civic, industrial and academic life of Sheffield were present to welcome the delegates. Apologies for their inability to attend were received from the Vice-Chancellor

of the University (Dr. A. W. Pickard-Cambridge), the Lord Bishop of Sheffield and the Provost and Archdeacon of Sheffield (the Very Rev. A. C. E. Jarvis, C.B., C.M.G., M.C., D.D., Chaplain to the King).

The Lord Mayor pointed out that the meeting was being held in the Mappin Hall, which was part of the University buildings, and it was a pleasing feature of the developments of the city life that there existed the very closest co-operation between the leaders of industry and the leaders of this great centre of learning. The relations which continued to exist between the University and the leaders of industry in Sheffield had in his judgment done much to stimulate the industrial recovery during the past two or three years, and as he rejoiced at the signs of improved trade and prosperity in the City, he realised that foundrymen had taken no small part in it. On behalf of the citizens, he extended to them the most cordial welcome.

Presentation of Meritorious Service Medal

The Lord Mayor then presented to Mr. H. Bunting (hon. secretary of the East Midlands Branch of the Institute) the Meritorious Service Medal in recognition of his past services.

The Secretary of the Institute (Mr. T. Makemson) explained that the Meritorious Service Medal was instituted two or three years ago, to be awarded, not necessarily every year, to a member of the Institute who had performed particularly meritorious service over a long period. This year the Council had decided to make the award to Mr. Bunting, and felt that in so doing they were fulfilling the intention, because Mr. Bunting had carried out the very onerous duties of hon. secretary of the East Midlands Branch for no less than 20 years.

Mr. H. Bunting, expressing his pride in having been awarded the medal, assured the members that his twenty years of secretaryship had been very happy years, and there was nothing connected with the work during that time with regard to which he had any regrets.

The Master Cutler (Mr. A. Williamson) extended a welcome to the Conference, on behalf of the Cutlers' Company, which was one of the most ancient companies in the country.

Last year the output of steel from Sheffield had constituted a record, for it was far greater even than during the war; it had amounted to 1,300,000 tons of steel last year. That had been made possible largely by the work carried out during the cleansing period, *i.e.*, during the years of depression. The people had not much work to do then, and had had plenty of time to think, and that time had been spent very usefully. The plant available was much more scientific and more efficient than that used previously, and production in that area had become much more economic than ever before in the history of Sheffield.

It afforded him the greatest pleasure, on behalf of the Cutlers' Company and the manufacturers of Sheffield generally, to welcome the Institute, and he hoped that all members would benefit from the Conference, both in mind and body.

The President of the Sheffield Chamber of Commerce (Mr. A. K. Wilson), who extended a hearty welcome on behalf of the Chamber of Commerce, said that founding was a very important branch of the Sheffield trade.

Vote of Thanks

The retiring President proposed a hearty vote of thanks to the Lord Mayor, the Master Cutler and the President of the Chamber of Commerce, and said the members appreciated very much the fact that, in spite of the many calls upon their time, they had found it possible to attend the opening of the Conference. He also took the opportunity to thank the Lord Mayor and Lady Mayoress for their very kind reception of the members at the Town Hall on the previous evening, and said it was gratifying that the Lord Mayor and the Municipality of the City appreciated that the Institute was worthy of a civic reception.

Mr. J. E. Hurst (President-Elect), seconding, said he hoped it was realised that the welcome accorded them in Sheffield was unique, for in no other city in Great Britain could they have been welcomed by a Master Cutler as well as by the Lord Mayor and President of the Chamber of Commerce. As President of the Sheffield Branch, Mr. Hurst took the opportunity to express, both on behalf of the Branch and the Organising Committee of the Conference, the heartiest thanks to the Lord Mayor and Lady Mayoress for their hospitality on the previous evening, which all members had greatly enjoyed.

The Lord Mayor briefly responded, and said that the Lady Mayoress and himself had indeed welcomed the opportunity of social intercourse with them, and so to widen the circle of friendships which he hoped was being formed during his year of office. The Lord Mayor, the Master Cutler and President of the Chamber of Commerce then withdrew.

Induction of New President

Mr. Stubbs then formally invested Mr. Hurst with the Presidential Badge and Miniature and installed him as the Institute's thirty-second President.

Presentation of Badges

Mr. Hurst having formally occupied the chair, amid prolonged applause, his first duty was to present the Past-President's badge to Mr. Stubbs, whom he hoped would continue his active association with the Institute and continue to give it the benefit of his advice.

Mr. Stubbs assured the meeting that he would be happy to render service to the Institute.

Mrs. Stubbs then presented to Mrs. Hurst the collarette and badge which is worn by the President's wife. She wished Mrs. Hurst the best of luck, and hoped that she would get as much enjoyment from the work as she herself

had done during the past year. Mrs. Stubbs also took the opportunity to express her gratitude for the kindness which had been extended to her personally during the past year.

Mrs. Hurst, amid applause, expressed her pleasure in receiving the collarette and her appreciation of the honour it carried with it.

The President took the opportunity to propose a vote of thanks to Mrs. Stubbs for her very able assistance to the President during the previous year.

The President then invested Mr. H. Winterton with the collarette of the Senior Vice-President.

Mr. C. W. Bigg (Junior Vice-President) was also accorded a hearty welcome in his new office.

Members of Council

The result of the ballot for the election of Members of Council was announced as follows:— *Elected for two years:* Prof. J. H. Andrew, Mr. V. Delport, Mr. E. Longden, Mr. P. A. Russell, Mr. D. H. Wood. *Elected for one year:* Mr. R. A. Miles (in succession to Mr. E. Stevenson, who has resigned).

Greetings from Overseas

The Secretary (Mr. T. Makemson) announced the receipt of greetings and congratulations from the French Foundry Technical Association, the Belgian Foundry Technical Association, the American Foundrymen's Association, Prof. Piwowarsky and Dr. Nipper, of the Technical High School, Aachen, Dr. G. Vanzetti, of Milan, and Dr. Geilenkirchen, on behalf of the German Foundry Owners' Association.

Welcome to Foreign Delegates

The meeting accorded a hearty welcome to Mr. W. A. Geisler, representing the German Foundrymen's Association, and who is a member of the Institute; and to Dr. Loeb, of the Molybdenum Company of America.

Mr. Hurst then delivered his Address.

PRESIDENTIAL ADDRESS

Mr. Stubbs and Gentlemen,—"*The renewed and extended interest in cast iron came as a surprise to those who believed the days of the ironfounder to be numbered, and was a revival which was as unexpected as it was pronounced.*"*

This paragraph in Prof. Turner's address over 25 years ago will serve to concentrate our attention on conditions as they exist to-day.

The remarkable developments which have taken place in the metallurgy of cast iron during recent years have been accompanied once again by a revival of interest, exactly as 25 years ago. It is not possible for me to deal comprehensively with all the developments which have accrued for the most part during the last ten years, but in selecting just one section of the metallurgy of cast iron, I have chosen that of its heat-treatment. I have chosen this because, in the first place it is a development which is as unexpected as it is pronounced, and in the second place it is a development which may be truly said to have originated in many of its directions in the Sheffield district. If I may add a third reason, it would be that I feel that the importance of heat-treatment of cast iron is only just beginning to be realised, and I am of the opinion that with further research and progress, the facility to heat-treat cast irons will play a vital part in maintaining and extending the industrial development of cast iron.

Heat-Treatment of Cast Iron

It is probably true to say that the heat-treatment of grey cast iron in various manners has been practised for a long time, but it is equally true to say that it was practised more or less surreptitiously. Engineers have looked upon it with disfavour and leading metallurgists in

* Professor Thomas Turner, Birmingham Conference of the British Foundrymen's Association, August, 1909. Address entitled "Twenty-Five Years of Cast Iron."

the past have categorically stated that by exposure to high temperatures cast iron is ruined. To-day, the position is completely changed, and metallurgists are able to show equally as emphatically that by exposure to high temperatures, as in correct heat-treatment, cast iron is not ruined, but actually its properties are considerably improved. The practice of heat-treatment in various forms has become firmly established and a substantial tonnage of cast-iron castings are heat-treated commercially and accepted by engineers without any qualms or misgivings as to inferiority in mechanical properties.

This change in view, in so far as hardening and tempering cast iron is concerned, has been brought about largely by the pioneer investigations of firms in the Sheffield district. Systematic experiments revealed the fact that cast iron could be hardened by quenching in water or oil from suitable temperatures. In this hardening condition, cast iron, when reheated or tempered at various temperatures, is softened to a varying extent according to the reheating temperature chosen exactly as in the tempering of steels. The exploration of the change in mechanical properties during such hardening and tempering treatments has now been carried out on a great variety of cast irons and alloy cast irons by a great many investigators throughout the world, and it has been clearly established that in the hardened condition prior to tempering a high degree of hardness is obtained, but is accompanied by mechanical weakness and a general lowering of the strength properties. The subsequent tempering treatment, however, has the remarkable influence of restoring the mechanical properties accompanied by a steady falling off in the hardness and a recovery of the machinability. Almost without exception it is found that tempering at a certain temperature yields mechanical-strength properties very substantially greater than the material in its orginal " as-cast " condition, and from diagrams showing the relation between

the properties in the "as-cast" hardened and tempered condition it will be seen that the tempering temperature/strength curves follows a course passing through a maximum at which the strength is higher than the original "as-cast" material. This critical tempering temperature varies probably with the particular composition and properties of the cast iron, but it is clearly indicated in all the numerous experimental results now available.

As would be expected, investigators have paid very great attention to the effect of such treatments on the brittleness, and this attribute of the mechanical-strength properties has been studied by utilising a variety of impact tests and also by the study of the resilience and the type and characteristics of the stress-strain curves. Here again it has been established that these properties in relation to the tempering temperature follow a similar course to the ultimate strength curve, and that with the correct heat-treatment the brittleness, rather than being increased, is actually diminished, and a degree of toughness substantially in excess of the original "as-cast" condition can be obtained. For example, this property has been studied for cast irons of varying phosphorus content, a constituent which is known to have an intrinsic effect on the brittleness of cast iron. It is found that the same rule holds, and even up to high percentages of phosphorus such as occur in some of our industrial cast irons, the strength properties, including the resistance to brittleness, are raised by suitable hardening and tempering treatment.

Alloy Additions

The discovery of the rational response of cast iron to hardening and tempering treatment has led to the study of the influence of alloy additions in respect to this treatment. Alloying elements, such as nickel, chromium, copper, molybdenum and others, have been carefully studied. As in the case of alloy steels, the influence of these elements on the critical speed of

cooling can be utilised for similar purposes, such as increasing the depth of penetration of the hardening effect, and nickel-chromium alloy cast irons suitable for air hardening are already in commercial use. The effect of these alloy additions on the capacity of cast irons for heat-treatment has already been of major importance in the economic justification of these additions to cast iron, as in the case of steels. An example of interest, and possibly of general importance, will not be found out of place.

In some experimental work in connection with a rather complex alloy cast iron containing aluminium, chromium and nickel, after exposure to temperature conditions in the neighbourhood of 500 deg. C. changes in mechanical properties were disclosed, which took the form of a marked falling off in tensile strength and resilience value. On the assumption of an apparent analogy between these phenomena and those of temper brittleness in steels, the effects of additions of molybdenum have been investigated, and quite a number of experiments show clearly that molybdenum, either alone or in conjunction with aluminium, does not bring about any reduction in strength after low-temperature treatment at 500 deg. C. under nitrogen-hardening conditions, and that it is also effective in preventing the reduction in strength under these conditions when nickel is present in the alloy. It is, of course, possible that this aspect of the influence of molybdenum is of importance in other considerations of this element in cast iron.

The microstructure of cast iron in the quenched condition is martensitic. As in the case of steels the structures on tempering pass through the troostite sorbite stages to pearlite. There is, however, an important difference between cast irons and steels in the part played by the graphite, and it is certain that the whole of the hardening effect is not brought about by the pearlite or that the initial presence of pearlite is necessary to ensure hardening. Recent experi-

mental work shows that the results obtained by heat-treatment are influenced also to an extraordinary extent by the form in which the graphite exists. For example, the hardening and tempering of cast irons having the ferrite/fine graphite structure has been accompanied by increases in strength of well over 100 per cent. in comparison with the untreated condition. The following experimental details are of interest in showing the effect of the amount and form in which the graphite exists.

These two specimens, prepared in exactly the same manner and differing only in phosphorus and combined carbon contents, showed a marked structural difference. Specimen 1 had an almost complete ferrite-fine graphite structure, and the fracture showed the characteristic appearance,

Spec. No.	T.C. Per cent.	Gr. Per cent.	C.C. Per cent.	Si. Per cent.	Mn. Per cent.	P. Per cent.
1	3.45	3.45	Nil	2.25	0.65	0.032
2	3.47	2.99	0.48	2.50	0.60	0.52

Moduli of as cast.	Rupture. Tons per sq. in.		Brinell. 2 mm. 30 kg.		
	H. & T. 275 deg. C.	H. & T. 450 deg. C.	As cast.	H. & T. 275 deg. C.	H. & T. 450 deg.C.
20.7	49.1	45.2	168	475	412
29.1	41.0	42.3	210	410	380

which has come to be known as "sooty graphite," whereas the second specimen showed normal graphite under the microscope and a characteristic bright fracture. In spite of the initial absence of combined carbon, specimen No. 1 hardens readily on quenching in oil from 875 deg. C. and attains a higher hardness value than No. 2 in hardening and tempering. In the "as-cast" condition, the lower strength-value

characteristic of the ferrite-fine graphite structure is found in specimen No. 1, but in spite of this, an increment of over 150 per cent. in strength is attained by hardening and tempering and the strength value attained is almost 25 per cent. higher than that attained by the coarse-graphite specimen. Not the least important of the possible lines to be pursued in further investigation is indicated by results of this order.

This reference to the effect of the graphite reminds me of the necessity of making further reference to the heat-treatment of malleable cast iron. Experimental work has shown that all varieties of malleable cast iron respond to hardening and tempering treatments and the effect on the strength properties of hardening and tempering treatments have characteristics similar to those outlined above. In this case, the elongation properties have to be taken into consideration also, and here it is possible to bring about a variety of changes by suitable heat-treatment. One important deduction from experimental results already published, for example, is that with a suitable heat-treatment by hardening and tempering, the properties of black-heart malleable can be made to resemble closely those of good white-heart malleable. This serves to emphasise a point of view that heat-treatments of this type are available for use in obtaining modifications in the mechanical-strength properties, and their sole value does not lie alone in their ability to produce hardened surfaces. This applies with equal force in the application of such heat-treatments to grey cast irons, and, I venture to predict, will assume far greater importance in the future metallurgy of cast iron.

Nitrogen Hardening

Quite a different form of heat-treatment is the nitrogen hardening process. This belongs essentially to the category of case-hardening processes and is carried out by subjecting the articles to the action of anhydrous ammonia gas at a temperature of approximately 500 deg. C. This

process, familiar in its application to suitable steels, was first extended to cast iron and a suitable alloy cast iron, now known as Nitricastiron, developed by the firm with which I am associated. This alloy cast iron is an aluminium-chromium alloy, and by treatment in ammonia gas, as mentioned, is capable of yielding surfaces of 1,000 Firth Diamond hardness and over. This is a development in the field of heat-treatment of cast iron as unexpected as it is pronounced, and has proved to be one of the utmost commercial importance. Its extension to other alloy cast irons is being actively pursued, and particularly in the case of austenitic cast irons it promises to be of equally great importance.

Temper Hardening

The discovery of hardening effects in alloys as a result of tempering, ageing and similar treatments is a general metallurgical development which has had important commercial results. Effects of a similar character have been noticed already in certain alloy cast irons, particularly those irons which come within the class known as austenitic cast irons. An interesting example of this is that of a nickel-manganese austenitic cast iron to the following composition:—Total carbon, 2.65 per cent.; combined carbon, 1.00; graphite, 1.65; silicon, 1.81; phosphorus, 0.074; sulphur, 0.025; manganese, 3.75; nickel, 6.50 per cent.

From a study of the dilatometer curves which revealed inflections at temperatures in the neighbourhood of 500 and 850 deg. C., it was concluded that in the normal condition the material was austenitic.

On passing a temperature of 500 deg. C. the austenite commenced to transform into martensite which was again transformed to austenite on passing the higher temperature of 850 deg. C. This alloy is clearly susceptible to temper hardening, due to the precipitation of martensite. The strength properties undergo a sharp increase on heating to 500 deg. C., and on heating to a further temperature in excess of

850 deg. C. the hardness and the strength values are lowered to approximately that of the original material.

In this necessarily brief review of the modern developments in the application of heat-treatments to cast iron, it is legitimate to take the view that their development, which is by no means small, has arisen out of the confidence inspired by the results of the research and investigation into the properties as affected by such heat-treatments. As in the case of other branches of metallurgy, they have assumed already a position of considerable importance. This may justify the selection of the subject for this presidential address, out of all the other truly remarkable developments in connection with the metallurgy of cast iron, which we have witnessed in this Institute during the last quarter of a century. These developments have made the metallurgy of cast iron quite a definite and distinct section of metallurgy. On all sides it has been recognised that remarkable advances have been made, but it is of greater importance to recognise that still further advances are possible. It is to be hoped that the developments in foundry education will direct the attention of students to this section of metallurgy and enable them to participate in its future progress. During the last year the Sheffield University has organised within its Faculty of Metallurgy a foundry degree course of training leading to a degree in foundry metallurgy. This opportunity for marked specialisation has been still further increased by the founding of the British Foundry School in Birmingham.

In closing, I propose to draw again on Prof. Turner's address to this Institute in 1909, over 25 years ago. It is now actually over 50 years ago since Prof. Turner presented his classical Paper to the Chemical Society in July, 1884. Prof. Turner is still with us, enjoying good health and full activity. As an honorary member of our Institute, we are proud to congratulate him on passing the Golden Jubilee of his monumental Paper. Foundrymen throughout the world will

share with him the immense pride in contemplating the more recent developments in the metallurgy of cast iron, of which he laid the foundation stone. The paragraph I would choose from his address of 1909 on which to close applies to-day with equal force as when uttered: "*Remarkable as have been the increases of knowledge during the past quarter of a century, it must not be supposed that all has been discovered, or that finality has been reached. In many directions we are yet only in the gateway of knowledge, and for the young and energetic investigator who has had the requisite training and skill, the field is as wide as ever before. Rather, it should be said, it is wider, for every firm foundation securely laid is but a stone on which to build, and through each doorway, which has now been opened, the earnest student sees long corridors as yet untrod.*"

Vote of Thanks to the President

Mr. Roy Stubbs (immediate Past-President), proposing a vote of thanks to the President for his address, said that one always expected something original from him, and by his presidential address he had certainly added to the many important contributions he had made previously to their knowledge.

Mr. H. Winterton (Senior Vice-President), seconding, also paid a tribute to the President; he commented with gratification on the fact that Prof. Turner, to whom reference was made in the address, was present at the Conference, and was still taking the greatest interest in the Institute; they all hoped sincerely that he would be spared for many years to continue his interest in it.

The vote of thanks was accorded with acclamation, and the President briefly replied.

The First Edward Williams Lecture

The President, in calling upon Sir William Larke to deliver the first Edward Williams Lecture, recalled that more than a year ago the Literary Committee and the Council of the

Institute had decided, in order to commemorate the very happy presidency of Mr. Edward Williams, to found an annual lecture, modelled somewhat on the annual lectures delivered before other scientific institutions both in this country and abroad. It was decided that the lecture each year should be delivered by a man who was prominent in his own sphere of industry or science and had taken an active part in the development of various aspects of scientific and industrial work.

Sir William Larke was so well known to the majority of those present that no formal introduction was necessary.

Sir William Larke, in his preliminary remarks, expressed his appreciation of the honour the Institute had done him in electing him an honorary member. Whilst it did not need that compliment to cause him to retain his interest in the progress and welfare of the Institute, one did appreciate the confidence of one's fellows, and he was indeed happy to receive such an honour from men whom he really knew, knowing that the honour was really meant.

Vote of Thanks

Prof. J. H. Andrew, proposing a vote of thanks to Sir William Larke for his lecture, said all would feel that justice and honour had been done to Edward Williams, whom they held in such high esteem and regarded with sincere affection.

The members deeply appreciated Sir William's lecture, and the film which he had brought at his own expense; even men of Sir William's outlook and energy could enjoy a good "movie." He had dealt with metals for many years, and he had always been sympathetic to man. His lecture was delightful.

Mr. V. C. Faulkner (Past-President), seconding, said it was particularly appropriate that Sir William had chosen the subject "Man and

Metal " for the first Edward Williams Lecture, for the study of early processes for producing metals was Mr. Williams' hobby, and he was searching for the earliest casting. He had recently visited the Far East in the prosecution of this research, and seemed to be on the eve of making the momentous discovery that all we have now had existed in China at the time of the Ling Dynasty.

The vote of thanks was enthusiastically accorded, and Sir William briefly responded.

Luncheon

The members and their friends were entertained to luncheon at the Grand Hotel, Sheffield, on Wednesday, by the Sheffield Branch.

Mr. A. Whiteley (President-Elect of the Branch) offered a hearty welcome to Mr. and Mrs. Hurst and to all attending the Conference, and expressed the pride of the Branch in the fact that in this Jubilee year one of its members should have attained the highest honour that the Institute could bestow. If, he said, Mr. Hurst had what he deserved, he would enjoy a very happy and prosperous year as President; the prestige of the Institute was great, and when the time came for Mr. Hurst to hand on his high office to his successor, he would be able to do so with the certain knowledge that the Institute was better and stronger by reason of his presidency.

Visits to Works

On Wednesday afternoon parties visited the works of Messrs. Steel, Peech & Tozer, Limited, Messrs. Hadfields, Limited, the Sheepbridge Stokes Centrifugal Castings Company, Limited, and the Foundry Department of the University of Sheffield.

Parties of ladies visited the factories of Messrs. Arthur Davy & Sons, Limited, and Messrs. Walker & Hall, Limited, while a third party inspected the new City Hall and the Central Library.

ANNUAL BANQUET AND DANCE

The PRESIDENT (Mr. J. E. Hurst) presided over a distinguished gathering, which included the Lord Mayor and Lady Mayoress of Sheffield (Alderman and Mrs. P. J. M. Turner), the Master Cutler (Mr. Alexander Williamson), Sir Harold Carpenter, F.R.S. (President, Iron and Steel Institute), Mr. A. K. Wilson (President, Sheffield Chamber of Commerce) and Mrs. Wilson, the Mayor and Mayoress of Chesterfield (Alderman H. Varley, J.P., and Mrs. Varley), Commander Sir Charles W. Craven, O.B.E., R.N., Mr. J. Ward, J.P., and Mrs. Ward, Mr. A. J. Grant, J.P., and Mrs. Grant, Mr. A. Whiteley (President, Sheffield Branch of the Institute) and Mrs. Whiteley, Mr. and Mrs. A. B. Winder, Mr. E. B. Gibson (Town Clerk of Sheffield) and Mrs. Gibson, Dr. W. H. Hatfield, F.R.S., and Mrs. Hatfield, Mr. and Mrs. P. B. Henshaw; Mr. F. M. Fisher (President, Refractories Association of Great Britain) and Mrs. Fisher, Mr. W. M. Gibbons (Registrar of the University of Sheffield) and Mrs. Gibbons, Mr. H. Winterton (Senior Vice-President of the Institute) and Mrs. Winterton, Mr. C. W. Bigg (Junior Vice-President of the Institute) and Mrs. Bigg, Mr. Barrington Hooper, C.B.E., Mr. and Mrs. C. K. Everitt, Mr. and Mrs. Joseph Ward, many Past Presidents of the Institute, and Mr. J. G. Pearce (Director, British Cast Iron Research Association).

The Toasts

MR. H. WINTERTON (Senior Vice-President) proposed "The City and Trade of Sheffield." Not only was Sheffield a city of modern repute; it had also a very interesting history. Among the many interesting developments which had originated in Sheffield, Mr. Winterton mentioned its introduction of cast steel in 1740, and the subsequent advancement in connection with steel from that time until the present era of stainless steel and other modern inventions. Sheffield was not

only in the forefront in regard to steel, however; many of the leading ironfounders of the district bore household names, names to be conjured with in the commerce of the universe.

Mr. Winterton coupled with the toast the name of the Lord Mayor, and paid a tribute to him in respect of his great public work as well as for the valuable support he had given to the Conference.

Sheffield's Industrial Development

The Lord Mayor of Sheffield said that Sheffield took pride in what it had done, and still continued to do, in regard to national trade recovery, and not the least interesting factor in that recovery was the wonderful system of co-operation which existed in Sheffield between the leaders of industry, the great University and the Technical College. It was proud of the wonderful research work carried out there during the past quarter of a century; industry used the research laboratories of the University, and that co-operation had been to their mutual advantage. Another development in which he took pride was the establishment at the University of the Foundry Degree Course within the Faculty of Metallurgy. This University, which he ventured to suggest was the premier in the country, had not the *éclat* of the older Universities; but it was because of its youthfulness and its determination to find a place in the sun that its work was so beneficial to the community. He again extended to the members a hearty welcome and hoped that when they left Sheffield they would carry with them the knowledge that the time spent there had been spent profitably.

The Lord Mayor, on behalf of the Sheffield Council, asked each of the ladies to accept a "pay envelope." Each envelope contained a handkerchief attractively coloured and decorated, being an example of the beautiful work turned out by the disabled soldiers at the Painted Fabrics Factory in Sheffield.

"Science Hand in Hand with Labour"

Sir H. C. Harold Carpenter, F.R.S. (President, Iron and Steel Institute), proposed "The Institute of British Foundrymen." Although, he said, the Institute was little more than thirty years old, the industry it represented extended back to the very beginnings of civilisation; indeed, its beginnings were lost in the mists of time, and it could be said with truth that every branch of industry to-day had resulted from the original discovery of prehistoric man—one of the greatest discoveries ever made—that it was possible to prepare a metal from a stone. When prehistoric man had done that and had worked out methods of founding, he had laid the foundations of everything they inherited to-day. Had that discovery not been made, there would have been no metallurgy to-day, and the face of the earth would have been quite different. Naturally, the development of metallurgy to its present stage had occupied a long time. The blast furnace, which was one of the founder's most important instruments of production, had needed about 2,500 years in which to mature. It was the most important instrument of production of the steel industry, on which the prosperity of Sheffield rested as much as it did on a plentiful supply of cheap iron. Apparently they did not realise fully to-day the enormous development made in the production of metals. Quite recently he had been interested to learn that more metal had been produced in this century than during the whole of the previous history of the world. That was a very remarkable fact.

The Institute's motto—"Science hand in hand with labour"—was very appropriate, because much of what was called "science" to-day had developed because of man's long and intense struggle with the properties of metals. The working out of their wonderful properties had been a very slow business; but the reasoning qualities of man had been developed in that way. After all, there had been introduced into our language various phrases which were based

on the properties of these wonderful materials; for example, the common phrases "as strong as iron" and "as true as steel," indicated that these qualities of metals had come to stand as standards of our conduct. If there were other substances which merited such a record he had yet to hear of them.

He referred to his early association with Prof. Andrew, who was his first and most precious student, and with Mr. J. W. Gardom (the Convener of the Institute's Technical Committee), who was his first laboratory assistant. It was a matter of very great delight to Sir Harold that two of that little band who had gathered in the very humble cellars of the University of Manchester had attained positions of such eminence and usefulness in the Institute.

Associating with the toast the name of Mr. Hurst, the President of the Institute, Sir Harold said he had had the privilege of his acquaintance for about 16 years. Mr. Hurst's name was very much identified with modern scientific work in connection with founding, and his work was known far beyond the limits of the Institute. One could not express the quality of his work better than by saying that it was widely known wherever founding was scientifically studied. Sir Harold had found Mr. Hurst's book on "The Metallurgy of Cast Iron" to be one of the very best books on the subject, and he paid a tribute to Mr. Hurst for having written it, so placing his knowledge at the disposal of his fellows.

The toast was received with musical honours.

The President's Reply

The President, responding, expressed the Institute's appreciation of the honour Sir Harold had done them in proposing the toast and his own personal thanks for the remarks made concerning himself. Naturally, he said, all the members were proud of the Institute, and all who had watched its growth during the past years were more than delighted that a man of

such outstanding eminence in the world of metallurgical science as Sir Harold Carpenter had found it possible to honour it in this manner. Whilst they all knew Sir Harold in his various metallurgical capacities, they knew him also as an honorary member of the Institute. They were proud of that, as they were also of the fact that his investigations were at one time concerned with cast iron, a material in which the Institute was so profoundly interested. The President held the view that the metallurgy of cast iron was rapidly becoming so vast that it demanded recognition as a distinct and separate section within the broader field of metallurgy; and Sir Harold's most exhaustive and comprehensive work on the growth of cast iron had laid the foundation of a very large section of the science of the metallurgy of cast iron. He ventured to think that that view was supported by a large number of the members of the Institute. His friend Dr. Hatfield had on one occasion suggested to him that cast iron metallurgists were opportunists. Whether or not Dr. Hatfield had made that remark jocularly the President was not sure, but he believed it was quite true, and it could be accepted as evidence of their vitality and their determination to further the development of this material amongst all those rapid developments which were taking place in metals and alloys to-day.

The intimate desire of all the members was to see the Institute expand and take its full place amongst the leading metallurgical scientific bodies throughout the world. This led him to a thought which he was anxious to take this opportunity to express. It was that, in his opinion, the continued development of the Institute could be served best by adding to its activities and associations all those things which added to its dignity and prestige. Associations such as it had formed already with the British Cast Iron Research Association, with the Sheffield University, through the new Foundry Degree Course within the Faculty of Metallurgy, and with the new British Foundry School, which had

been formed in Birmingham, were typical. If the direction of the Institute were concentrated on those lines he was certain that it would be to its benefit and to the gratification of its very exacting treasurer, Mr. W. B. Lake.

The President took the opportunity to express his personal thanks to all the officers of the Sheffield Branch for their unstinted help and work in the organisation of the Conference. None of them would object to his singling out the names of the Hon. Convention Secretary, Mr. T. R. Walker, and also that of the Branch-President, Mr. A. Whiteley. The President also thanked the Institute's Secretary, Mr. T. Makemson, for his kindly help and assistance, and also Mr. Roy Stubbs, the immediate Past-President, for his energy and determination. Mr. Makemson had made a good many visits to the organising meetings in order to give the benefit of his advice and help, and he had travelled from Manchester on each occasion to do so.

Finally, the President expressed his personal gratitude to his colleagues and the directors of the two companies with which he was associated, *i.e.*, Messrs. Bradley & Foster, Limited, and Messrs. Sheepbridge Stokes Centrifugal Castings Company, Limited, for without their assistance and forbearance in matters which ought to have been done and matters which ought not to have been done, he could not imagine how he could have undertaken the duties of the Presidency.

The Visitors

Mr. Arthur Whiteley (President, Sheffield Branch of the Institute) proposed the toast of "Our Guests." He took the opportunity to extend a special welcome to the Lord Mayor and Lady Mayoress of Sheffield. The members of the Institute were particularly glad to have this opportunity of acknowledging in a small way their gratitude to the Lord Mayor and Lady Mayoress for the generous hospitality and entertainment they had afforded at the Town Hall on the previous evening. They were proud, too, that the

Master Cutler had honoured them that evening. Mr. Whiteley also extended a very hearty welcome to Sir Harold Carpenter. They were indeed very grateful to him for honouring the Institute with his presence that evening, and thanked him sincerely for having proposed the toast of "The Institute" in so charming a manner.

Other guests whom he mentioned particularly were Mr. A. K. Wilson, President of the Sheffield Chamber of Commerce, and Mrs. Wilson; Mr. W. M. Gibbons, Registrar of the University, and Mrs. Gibbons; the Mayor and Mayoress of the neighbouring town of Chesterfield; the Town Clerk of Sheffield and Mrs. Gibson; also many leading industrialists—Commander Sir Charles Craven; Mr. and Mrs. Winder; Mr. and Mrs. A. J. Grant; Mr. and Mrs. C. K. Everitt; Mr. and Mrs. Joseph Ward and many others, and also other gentlemen representing kindred and allied associations, such as Mr. J. G. Pearce, Director of the British Cast Iron Research Association, and Mr. F. M. Fisher, President of the Refractories Association of Great Britain; and they must not forget, of course, their friends who represented the daily and technical Press.

There were two gentlemen to whom he referred specially, namely, Mr. T. R. Walker, the Conference Secretary, and their well-tried and trusted Branch Secretary, and also Mr. Tom Makemson. They were very grateful indeed to both for their wonderful work. On their shoulders had fallen the great bulk of the work in the organising of the Conference, and Mr. Whiteley said he was sure that the President would wish him publicly to express gratitude to these gentlemen.

He had great pleasure in coupling with the toast the name of Mr. P. B. Henshaw, a gentleman well known in the locality, whom they were always delighted to meet.

Mr. P. B. Henshaw, on behalf of the guests, congratulated Mr. Hurst on having attained the high office of President, which they knew he

would occupy with satisfaction. His energy, his capability and that pleasant manner of his had endeared him to all his colleagues in the Sheffield district and, one was perfectly certain, to all members of the Institute. The guests would like to congratulate both Mr. Hurst and the Institute on Mr. Hurst's election and to wish them all a very happy and successful year.

He also took the opportunity to compliment the Sheffield Branch upon having secured as its President a man so energetic as Mr. Whiteley, whose capabilities also had been well proved. The guests were very happy in the knowledge that, as Mr. Whiteley had stated, they were chosen guests, chosen to meet the members of the Institute, and to enjoy with them a very happy evening.

Presentation to Mr. Walker

Mr. John R. Hyde expressed thanks on behalf of the Council of the Sheffield Branch of the Institute to Mr. T. R. Walker for his great services as hon. convention secretary and secretary of the Sheffield Branch, and presented to him, also on behalf of the Branch, a four-piece silver tea service as a mark of appreciation of those services. Mr. Walker's work, he said, was very highly appreciated, and it was felt that this banquet would provide a very suitable occasion to make a presentation to him. The present took the form of some old Sheffield plate. Inasmuch as Mr. Walker was very interested in developing and improving the craftsmanship of Sheffield, it was fitting that the Branch should present him with some old Sheffield plate which would always serve as a reminder of his connection with the high standard of craftsmanship of the City. The presentation comprised four pieces, and it was hoped that they would serve always to remind him also of his very happy connection with the Sheffield Branch of the Institute, as well as affording some recompense for the very hard work he had put in on behalf of the Branch.

Mr. Walker, expressing his thanks for the kindly thought which had prompted the gift, assured the members that the work of organising the Conference had been extremely pleasing, and it had been rendered all the more pleasing by the kindness of the firms in the Sheffield district who had been so very generous in their support. It was a sign of the times that they were so ready to help the Institute.

During the evening music was provided by Victor Haythorne and his orchestra. There was also very amusing entertainment by the renowned "Stainless Stephen," who made some very apt comments on the alleged activities of some of those present, and a cabaret was arranged by Mrs. Amy Twigg.

THURSDAY, July 4th

The Conference was resumed at 9.30 a.m., and a Paper, on "Some Notes on Ingot Moulds," by Dr. T. Swinden and Mr. G. R. Bolsover was presented and discussed, the President presiding.

During the remainder of the morning duplicate sessions were held. Session A, under the chairmanship of the Senior Vice-President, Mr. H. Winterton, was devoted to a symposium of Papers on Steel Foundry Practice, the following Papers being presented:—

"Steel Castings, with special reference to Alloy Steels," by W. H. Hatfield, F.R.S., D.Met.

"Research on Steel Castings," by Prof. J. H. Andrew, D.Sc.

"A Note on the Influence of Temperature Gradients in the Production of steel Castings," by G. Batty. (American Exchange Paper.)

"Castings," by W. Machin and M. C. Oldham.

The President presided over Session B and the following Papers were presented:—

"The Making of Large Castings by Loam Moulding," by H. Fabre and H. Dubois. (French Exchange Paper.)

"German Iron Foundry Progress in Piston Rings, Brake Drums and other Automobile

Castings," by W. A. Geisler. (German Exchange Paper.)

"Relationship in Cast-Iron Test Results," by G. L. Harbach.

The Conference adjourned at 12.30 p.m. and members and ladies lunched together at the Grand Hotel.

Thursday's Works Visits and Reception

In the afternoon parties of members visited the following works:—The Grimesthorpe and Vickers works of the English Steel Corporation, Limited; Newton Chambers & Company, Limited; General Refractories, Limited, Worksop, and the research laboratories and high-frequency induction furnaces of the United Steel Companies at Stocksbridge. Visits were also arranged for the ladies, a large number of whom inspected the manufacture of fancy goods by disabled soldiers and sailors at the workshop of Painted Fabrics, Limited. Another party studied the making of biscuits by Messrs. W. Gunstone & Sons, Limited, and a small group spent a very interesting afternoon at the printing works of the "Sheffield Telegraph."

On Thursday evening members and ladies were entertained at a very charming social function at the Western Bank Buildings of the University. The guests were received by Colonel H. K. Stephenson, D.S.O., the Pro-Chancellor, the Vice-Chancellor, Dr. A. W. Pickard-Cambridge, and Mrs. Pickard-Cambridge. The beautiful Firth Hall was available for dancing and the guests inspected various parts of the building, considerable interest being shown in the library, which contains many valuable first editions. Refreshments were provided in the University refectory.

The Institute is indebted to the University of Sheffield for many courtesies and considerable assistance in connection with the Conference arrangements, but all who were present felt that the hospitality of the University reached its highest level in the very delightful entertainment which was accorded to the visitors.

The Garden Party at Hope

Members and ladies were able to enjoy some very beautiful scenery in the course of an excursion which took place on Friday, July 5. The party travelled by motor coach along the Derwent reservoirs via Ashopton, in the valley of the Derwent. Returning down the Derwent valley, lunch was served at the Marquis of Granby Hotel, Bamford. After lunch the drive was resumed through the village of Castleton to a point beyond the village commanding a wonderful view of the beautiful Hope Valley. At the Rising Sun Hotel, at Hope, the party were the guests of the President and Mrs. Hurst at a garden party.

After tea, Mr. H. Winterton, Senior Vice-President, voiced the thanks of the party to Mr. and Mrs. Hurst for their hospitality, and also took an opportunity of expressing the thanks of all the members and ladies to the Sheffield Branch for the extraordinarily successful arrangements they had made for the Conference. He particularly stressed the debt which the party owed to Mr. T. R. Walker, the honorary conference secretary, for the indefatigable work he had carried out over many months, and congratulated Mr. Walker upon the success of the organisation. Mr. Winterton's remarks were supported by Mr. Bigg, the Junior Vice- President. Mr. Hurst replied on behalf of Mrs. Hurst and himself, and Mr. Whiteley, President of the Sheffield Branch, and Mr. Walker responded on behalf of the Branch. Mr. James Smith then proposed the toast of "The Ladies," to which Mrs. Hurst replied in a charming little speech.

EDWARD WILLIAMS LECTURE

MAN AND METAL

By Sir William J. Larke, K.B.E. (Director of the British Iron and Steel Federation)

I am deeply sensible both of the honour and of my own inadequacy in being invited to deliver the first Edward Williams Lecture,

founded out of compliment to our former President, Mr. Edward Williams, as a mark of the esteem in which he is held by the members of this Institute and in recognition of his particularly successful year of office. We all appreciate how greatly he distinguished that office by his assiduous attention to the duties and responsibilities of the position. May I be permitted to add that Mr. Williams was No. 1 on the roll of the University College of Cardiff when it was founded some fifty years ago. We trust that we may long have him with us to add wisdom to our Councils and distinction to our membership.

When we consider our dependence on metals to-day, their paramount influence on the development of mankind and our intellectual and material civilisation, it is remarkable that, although it is generally accepted that man first appeared on the earth 300,000 years ago, there is no conclusive evidence that he had any knowledge of metals earlier than 4,000-5,000 years before the Christian era; say the last 7,000 years. It is only in the last 200 years that metals have rendered possible that revolution which converted handicraft into industry. During the present century more metals have been produced than during the whole period of historic time preceding the year 1900.

Immediately preceding the Metal Age was the Neolithic or late Stone Age. Knives, scrapers and weapons consisted of stones selected or chipped into shape for the purpose required. A considerable degree of skill in their manipulation was developed, particularly when it is borne in mind that the stone used was largely flint. The earliest use of metal was in its native form, when it was considered as a malleable stone.

Rickard in "Man and Metals" assumes that there was a transitional period between the Stone and Metal Age, which he has called the Chalcolithic or copper stone period. Copper was the first metal known, at least in the Ancient World, Egypt and the East, where the evidence of actual specimens is supported by writing and pictorial representation. According to Partington

there is evidence that in pre-historic times galena or lead sulphide, which was probably not recognised as a metal, and malachite, natural copper carbonate, were used as eye paints.

Copper Smelting

Copper smelting was probably discovered about 4500 B.C. and no doubt accidentally. One authority suggested that a woman of the period dropped her malachite face powder or paste accidentally into the fire and the resulting copper bead was discovered. Most authorities, however, agree that it is much more likely, as with all metals, that smelting was an accidental discovery following a camp fire which had been built in a circle of stones containing ore, and that beads of copper were observed on the stones when the fire was extinguished and recognised as being the same as the native metal with which they were already familiar. This is substantiated by a similar experience recorded in modern times in the copper-bearing districts of Rhodesia.

The working of copper appears to have reached a relatively high standard in very early times, as prior to 3400 B.C. worked copper included sheet and wire needles with eyes bent over as loops, pins, beads, bracelets and copper bands. The wire was made by slitting sheet, which latter had been produced by hammering, and the slit strip was actually hammered round. About 3000 B.C. copper was used for bolts and nails, hinges, wrought table vessels, cups and even doors. A copper welded drain pipe 4.7 cm. in diameter and 1.4 mm. thick was discovered on a site indicating that it had been 400 m. long, and could be dated 2500 B.C.

Following copper was, if not the discovery, which probably preceded copper, at least the use of gold for decorative purposes about 3500 B.C. It was used in the form of a thin leaf for gilding teeth, finger nails and toe nails. Gold leaf was also applied to copper with stucco; firing was not understood until much later. The development of smelting brought more metals to the

notice of man. Bronze, which appears about 1,000 years later than copper, was the result of smelting mixed ores, and tin was not separated until much later.

Bronze represented a considerable advance with its lower melting point, and greater beauty and hardness. Ancient bronze varies in its constitution from about 77-95 per cent. copper content. Bronze and copper roofs are mentioned as being used in Babylon. Bronze daggers, razors and weapons were common in Egypt in 2000 B.C. It is suggested that the discovery of bronze was probably made in Khorasan, Northern Persia, where tin and copper are mined together.

Lead, produced before 3400 B.C. in sheet form, was actually used as a damp course in the walls of Babylon. It was not, however, used to any great extent until the 6th century B.C., when it was used for water tanks. Brass, which was probably also an accidental alloy, was known in Palestine as something distinct from copper about 1500 B.C. Some confusion exists with regard to it, owing to the application of the term by early writers to a variety of metals and alloys, such as copper, electrum, bronze and even alloys of iron.

Partington, in "Origins and Development of Applied Chemistry," to whom I am indebted for much of this chronology, says that zinc oxide is mentioned as an eye salve in the Ebers Papyrus in 1550 B.C., and antimony is also mentioned as a medicine in this case for internal use. Mercury was imported into Egypt between the 15th and 16th centuries B.C., presumably from Spain. Copper, which was largely used for tools and weapons, being hardened by cold-working, was subsequently replaced by bronze, which was harder still and could be made to take something of an edge, and which formed the basis of weapons even up to Roman times. It was, however, the discovery of iron which gave the greatest impetus to the development of man, both intellectually and materially.

Meteoric Iron

There seems no doubt that the earliest iron worked by man was of meteoric origin. Zimmer, who examined this question very thoroughly, seems to have demonstrated conclusively that this was almost certainly the case. He has proved that at the date of his examination (1916) upwards of 90 per cent. of the then known meteoric iron (250 tons) was ductile.

The earliest iron remains contain a substantial percentage, upwards of 3-7 per cent., of nickel, characteristic of meteoric iron. This explains the observed freedom from corrosion and the ability to take an edge, which has characterised some of the earliest iron weapons. The meteoric origin of iron is supported by the traditional name for iron in many cultural languages, which, when literally translated, means something hard from Heaven. A Pyramid text of 2750-2450 B.C. calls it "metal of heaven." A Hittite text of 1400 B.C. mentions black iron from the sky (Rickard).

Cortez, in the early part of the 16th century, when he conquered Mexico, discovered that the Aztecs valued iron knives and daggers far above their gold, and when asked how they produced it, they said it came from the sky. It is a curious commentary that these statements were dismissed as mythical, and, according to Zimmer, it was not until April 26, 1803, when a shower of meteorites was observed at L'Aigle, Normandy, by some thousands of people, that the celestial origin of meteoric iron was accepted in modern times.

Smelting of Iron

The date and place of the origin of iron smelting cannot be definitely determined. The earliest iron weapon discovered in Egypt was a spearhead of about 2000-1800 B.C. This must have been imported. There is evidence that iron was used in Babylon about 2500 B.C., and became comparatively common in 1400 B.C. in the form of steel showing carburisation. The smelting of iron as a craft appears to have originated on

the shores of the Black Sea, where there was available a particularly pure magnetic iron sand. The Taurus Mountains and the foot of the Caucasus are also suggested, as the local ore contains manganese, and a good-quality iron was produced.

The most famous iron remains in Europe are the finds in the graves at Hallstatt, Carinthia, Austria, of iron and bronze weapons of similar types and shapes, indicating the transition from the Bronze to the Iron Age. These can be dated at about 1200 B.C. The Iron Age in India has also been dated between 1400 and 1300 B.C., where there was a highly-developed iron craft in Hyderabad, from which originated the famous Indian steel called wootz, produced by a cementation process, similar to that invented by Huntsman in 1740. Although iron was reduced from the ore, it was not melted, since the temperature could not be raised in primitive furnaces to its melting point. The iron produced was a spongy mass mixed with silica and ash and other impurities. It was purified by continual reheating and hammering, and although there was some evidence to show that cast iron was occasionally produced, it was rejected as being brittle and non-malleable.

Originally the smelting of ore was carried out simply by a fire laid in a hole in the ground, ore and fuel being mixed together, and the temperature reached was simply that obtainable by natural draft or by surface fanning. There was then added a clay lining to the hole, the addition of a trench in the ground leading to the hole in the direction of the prevailing wind, and finally to a small superstructure above the ground, in which were inserted clay pipes or tuyeres at ground level, through which was blown an artificial blast from skin bellows. The clay lining of the furnace was the forerunner of the crucible and the superstructure and bellows of the blast furnace. There is pictorial evidence of the use of bellows in Egypt in 1500 B.C., but the liquefaction of iron had to

wait upon the use of the power-driven bellows which were not available until the 14th century A.D., when they were driven by water wheels. Thus, Rickard points out, there was a period of 2,500 years between the making of wrought iron and the art of casting it.

Iron as Currency

The Iron Age does not seem to have commenced in Britain until about 400 B.C., and Ault suggests that from the general introduction of iron tools and weapons may be dated the development of man from a hunter into a farmer. As the result of storing food supplies, domesticating animals and through the exchange of food for tools and weapons, he became a trader and a capitalist. It is significant that iron was used as currency in the shape of bars in this country, a practice that was probably introduced from the East, since Rickard records that a store of iron belonging to King Sargon II at Khorsabad, 722-705 B.C., consisted of bars of iron from 9 to 12 in. long and $2\frac{3}{4}$ to $5\frac{1}{2}$ in. thick, weighing 9 to 44 lbs. each, the total weight being 176 tons, each bar being pierced at one end for transport. Included with this store were many finished articles, such as chains and horses' bits, etc.

From this period for the next 2,000 years, while the use of metals became more common, it may be said that their application did not change in character. The principal advance was the introduction of cast iron about A.D. 1340. Cast iron was not converted into malleable iron until the invention by Cort of the puddling furnace 440 years later. Thus, while metals were made to contribute to the welfare and comfort of mankind over a wider area, the technology of their production and use made comparatively small advance. Richardson, in "Prehistoric Iron," says the chemistry of the process (of the production of iron) was as vague to the European of A.D. 1700 as to his Celtic predecessors.

The products of the early craftsman, 2,000 to 3,000 years B.C., were as good of their kind and showed a degree of skill at least equal to that shown by the craftsmen in similar things up to even the 16th and 17th centuries. In the later centuries, of course, mechanism developed to an extent previously unknown, producing clocks, combination locks and other things of this kind made of iron. As production was simplified and the use of metal tools, for agriculture and handicrafts generally, as well as for weapons of war, became more widespread, they became available to a much greater number, and thus unquestionably raised the standard of life of the people as a whole. No doubt this development also tended to create classes of society, since metal tools and weapons were a form of wealth which could be accumulated, and those who possessed them obtained a measure of economic and physical advantage over their fellows.

Three Phases of Industrial Development

In this country there have been during the historic period, say from the date of the Norman Conquest, three main phases of industrial development. The first and longest was a continued development of metal handicraft, and lasted until the early part of the 18th century, the second the age of coal and iron, and the third commencing with the present century, the age of alloys and electricity. The second phase lasted only a century and a half, and dated from what has been aptly described by Rickard as the marriage of iron and coal, the High Priest of which was Abraham Darby, who first used coke in blast furnaces in 1735, after experimenting for some years. To obtain his blast he used a water wheel some 24 ft. in dia. and pumped the water from his lower mill pond into the upper with a Newcomon fire engine. This application coincided with the improvements in the steam engine, due to James Watt, which provided the blowing power enabling the iron masters to produce iron in bulk at a much lower cost than was previously obtainable. This made

possible the development of the steam engine and all that flowed from it, by providing the materials in the form of cast and wrought iron in quantities which permitted the application of the steam engine for pumping and general power purposes.

The Railway Era

There followed within the next century perhaps the most active period in human history of invention and economic and cultural development. Stephenson's first locomotive in 1815 marked the birth of the railway era. Rails were originally of cast iron, then of wrought iron, made possible by the invention by Cort of the puddling furnace and grooved rolls in 1783 and 1784 respectively. The first steel rail made at Dowlais in South Wales was laid in 1857. In less than a century, according to Carpenter, there were no less than 800,000 miles of railway laid in the world.

In this country railway development was very rapid. Whereas in 1840 there were 1,331 miles of track, by 1890 this had reached 20,000 miles. The reason was the rapid development of the Machine Age between the middle of the 18th and the middle of the 19th centuries. The conversion of handicrafts in the home to industry in the factories had proceeded with such rapidity that industrial production had outstripped the capacity of accessible markets to absorb it. Only horse transport was available, or to a limited extent water on the coast and inland rivers. Industries had been located where coal and other raw materials were to be found, such as the Black Country for the metal industries and Lancashire and Yorkshire for the textile industries. The railways found immediate employment in transporting the surplus industrial production to markets further afield, and also in opening up new sources of supply of raw materials.

It is remarkable how short a period has elapsed since the speed of transport exceeded that of the horse. It was as late as 1829 that Stephenson's Rocket won £500 for maintaining

an average speed of 44 miles per hour over 35 miles. In 1904, 102.3 miles per hr. was reached on the Great Western from Plymouth to London, and during the present year the L.N.E.R. reached 108 miles per hr. in ordinary running between Grantham and Peterborough. As regards the motor car, Sir Malcolm Campbell reached 272.82 miles per hr. at Daytona on March 7 of this year. The aeroplane record is held by Italy 423.57 miles per hour, being attained at Lake Garda on April 10, 1933. The "Normandie" has recently maintained an average of 30.91 knots for 24 hours in crossing to America.

The Electric Age

At the beginning of the 19th century the discoveries of Volta, and particularly that of electro-magnetic induction by Faraday in 1831, mark the birth of the Electric Age in which we are now living. Although the dominant metal is iron and its various alloys, this discovery brought copper into its own. First, the invention of the telegraph in the early forties by Wheatstone and others, the development of the dynamo for electro-plating in the forties and for electric light in the next decade, marked the beginning of the era of the electric transmission of power. From the small ring, 6 in. in dia., which Faraday made to demonstrate electro-magnetic induction, has grown the modern electric transformer of 100,000 kilowatts. From the fine copper wires used for transmitting the small battery current required for telegraphy between Euston and Chalk Farm in 1843, has developed not only the cables which cross the oceans of the world, but the electric transmission systems which form a network covering most of the industrial countries.

In this country the electric grid already comprises 4,000 miles of transmission line, and is the result largely of the development in the last twenty years of the production of aluminium, the most efficient electrical conductor per unit of weight, which was only discovered in 1825

little more than a century ago. It remained throughout the 19th century something of a curiosity, but is now one of the most important metals and seems destined to fill an even more important *rôle* in the future.

In the electric grid in this country 12,000 tons of aluminium have been used for transmission lines, and the supporting towers have required 150,000 tons of steel. At Dagenham the span across the river is 3,060 ft. and the towers to support it are the highest in the world, being 487 ft. high, upwards of 80 ft. higher than the cross of St. Paul's, weighing 290 tons each. A special alloy has been used for the lines of phosphor-bronze and cadmium.

Cast Iron as Structural Material

Although the present appears to be dominantly a Steel Age, actually cast iron is still one of the most important structural materials. The necessity of increasing its malleability and tensile strength has resulted in the production of cast iron with a tensile strength of 32 tons per sq. in.; and of a foundry technique which can provide it with a glass-hard surface and capacity in the body of the metal to withstand substantial shock.

We are apt to forget what an important structural material cast iron is to-day. The tube railways of London are built of cast-iron sections, of which approximately 1,000,000 tons is already erected. The latest development of this technique is the tunnel under the Mersey between Liverpool and Birkenhead, which contains no less than 80,000 tons of cast iron. The road is paved with cast-iron blocks with non-skid glass-hard surface.

The evolution of the use of metals appears to have passed through a stage, first by manipulation by forging, secondly, by casting, and then—the present method—casting and subsequently mechanical manipulation, forging, rolling, etc. All metals used to-day are first cast before they are otherwise treated or manipulated, and it is at the casting stage that the metals or alloys

receive their basic characteristics on which depend their ultimate qualities. It is for this reason that we have no less than four important research organisations dealing with casting: the Cast Iron Research Association, the Steel Castings Committee, the Heterogeneity of Ingots Committee and the Non-Ferrous Metals Research Association, which is doing important work on casting.

Sheffield, which was known for its cutlery in the days of Chaucer, occupies a prominent position as the centre of metallurgical discovery and development during the present century, which has rendered modern engineering achievement possible.

Manganese and Silicon Steel

Manganese and silicon steel were discovered by Sir Robert Hadfield in the eighties of last century, but it was not until 1903 that the properties of silicon steel for use in electrical transformers and machines began to be appreciated; it has been used generally since 1907. Its use resulted immediately in halving the magnetic iron losses, and to-day the losses which represented 5 per cent. of the output before the introduction of silicon steel are reduced to between 1 and 2 per cent. It is not too much to say that modern electric transmission and the large generating units now used would have been impossible without this discovery.

Manganese steel, owing to its wearing qualities and resistance to abrasion, giving twenty to thirty times the service of steels used previously, has exercised a profound influence on railway development, and has made available heavy machinery for civil engineering work which otherwise could never have been undertaken.

Discovery of Chromium-Nickel Steels

One of the most important metallurgical developments of the last twenty years has been the production of a series of steels containing varying amounts of chromium and which, when tested in nitric acid, were found to have progressively increased passivity proportional to the

increase in chromium. This phenomenon, discovered at the Brown-Firth Laboratories, Sheffield, by Mr. Harry Brearley in 1913, may be said to have introduced an entirely new field of application for rustless steel in cutlery, industrial machinery, chemical plant, steam turbines, valves for all purposes, and other uses too numerous to specify, where high mechanical properties and non-corrodibility are essential. It is even largely used for decorative purposes, particularly where exposed to atmospheric corroding influence.

This series of chromium-nickel steels has already been developed with a wide range of mechanical and heat-resisting properties. It may be claimed as one of the greatest discoveries of the present century, the full extent of the application of which cannot yet be foreseen.

In the case of tool steels, of which again Sheffield is the recognised centre of origin and production, the progress during the present century is remarkable, and illustrates the important contribution of the rarer metals when alloyed with iron in the production of materials on which we are to-day dependent. In the early part of the century, about 1910, steel containing 0.6 to 0.8 per cent. of carbon, 3 to 4 per cent. of chromium, 18 per cent. of tungsten and 1 per cent. of vanadium, had given a cutting speed of 3 lbs. per min.

Cobalt was the next element, and certain tool steels to-day, containing carbon, chromium, vanadium, cobalt and molybdenum, are capable of removing 10-12 lbs. of metal per min. and retain their hardness at red heat. Thus manganese steel, which previously was considered for all practical purposes non-machineable, is now machined quite successfully.

Still harder alloys of non-ferrous metals for cutting tools are now available, such as stellite, a cobalt-chromium-tungsten alloy and another class known as the tungsten-carbide alloys, are made by compressing metals in powdered form with the addition of cobalt to provide cohesion. These are capable of removing 16.8 lbs. of metal

per min. The importance of these non-ferrous alloys is that their hardness is such that many materials previously considered unmachineable can now be machined, including glass, porcelain, hardened steel and chilled iron. The extension of power which these products give to the engineer is almost incalculable. The development of steels with higher tensile properties has also enabled the engineer to use higher peripheral speeds, and higher pressures at higher temperatures in steam turbines. While the credit is the engineer's, the realisation of his inventive genius was not possible until metals capable of withstanding very high stresses at high temperatures were available.

To-day it is possible to build turbines of 30,000 kilowatts running at 3,000 r.p.m. The higher steam pressures used are only made possible by the use of steels of the nickel-chromium-molybdenum series. It has been proved possible to operate a turbine successfully of 10,000 kilowatts, 3,600 r.p.m., continuously at a temperature of 1,000 deg. Fah. Similarly, the peripheral speed of turbine buckets has increased from 870 ft. per sec. in 1918 to 1,250 ft. per sec. in the present day, solely on account of the improvement in materials which has resulted from the work of the research laboratories of the steel industry in Sheffield and elsewhere.

Aviation and the Motor Car

The contribution of metallurgy to aviation is equally great. The first radial aero engines, which are about 15 years old, weighed 2 lbs. per brake horse-power. In the latest type this has been reduced 1.2 lbs. The six-cylinder engines used during the war had a weight of 2.65 lbs. per brake horse-power. The most modern engine of a similar type in normal use weighs under 1½ lbs. per brake horse-power. The Schneider Trophy engine weighed ¾ lb. per brake horse-power. This was designed for a limited period of service, whereas the ordinary aviation service requires that an engine should run for

500 hrs. without a serious overhaul. However, authorities I have consulted consider it probable that aircraft engines for ordinary service in the near future will be reduced to a weight of about 1 lb. per brake horse-power.

The development of the motor car during the present century is equally impressive, largely due to the development of light alloys. In 1900 the maximum piston speed was of the order of 1,500 ft. per min. To-day 3,200 ft. per min. is common practice. Whereas in 1900 a 10-h.p. engine was of the order of 3.5 litres cylinder capacity at a maximum speed of 1,600 r.p.m., to-day a similar engine has a capacity of 1.2 litres and a maximum speed of 4,500 r.p.m. The output of the 10-h.p. engine has increased from approximately 17 to 30 brake horse-power, 1.8 times, due to the increase in mean effective pressure and piston speed, both of which have only been made possible by metallurgical progress.

Of recent engineering triumphs, perhaps three of the most outstanding based on steel are in order of time the Sydney Bridge with a span of 1,650 ft. across Sydney Harbour, the arch of which contains 38,000 tons of special high-tensile steel, which alone may be said to have rendered this design practicable; the Irak oil pipe line, 1,200 miles long, a triumph not only of civil engineering, but of the production and manipulation of the material of which it is made, being welded throughout, including the joints; the "Queen Mary," which, when launched, was claimed to be the largest mass—40,000 tons—ever moved by man unaided by mechanical power.

The Duralumin Alloys

The duralumin series of alloys, invented in the present century, consisting of approximately 90 per cent. aluminium with varying proportions of copper, manganese, magnesium, silicon and iron, having the strength and hardness of mild steel and only approximately one-third of its weight, has made modern aviation possible, in the design of the aeroplane.

The increasing use of the rarer metals is a particular feature of the twentieth century; osmium, tantalum, tungsten in lamps; magnesium, chromium, tungsten, molybdenum, vanadium, cobalt, nickel, beryllium, cadmium alloyed with iron, and also copper, lead, generally in very small proportions, provide, however, the dominant influence in producing the characteristics of the alloys of which they form a part. Radium and selenium have more special applications. The application of these rarer metals has enabled the efficiency of electric incandescent lamps to be increased from 3.1 lumens per watt to 11.5 within the last thirty years. The consumption of lamps in the British Isles for ordinary service has increased from 20 millions in 1922 to 65 millions in 1934. The cost per unit of light has been reduced to one-third, when calculated on a rate of only 2d. per kilowatt hour.

Broadcasting, the full significance of which cannot yet be appreciated, is perhaps the most remarkable application of scientific discovery in our daily life, and this is ultimately dependent on the work of the metallurgist. This brief summary shows that metallurgical progress in the present century has been almost as great as in the whole previous history of mankind.

World Production

The growth of the Metal Age cannot be better illustrated than by a comparison of the world production of the various important metals since 1900 up to recent times. The following table has been specially prepared by the Mineral Resources Department of the Imperial Institute. From 1900 to 1929, the peak year, the world production of steel was multiplied over four times, of copper approximately four times, and of aluminium no less than 35 times. Although the quantities of the rarer metals are much smaller, the rate of increase in their production is no less impressive and significant.

If this brief survey has demonstrated the important part which metallurgists have played in

the development of our modern material civilisation, it none the less indicates the potentialities of the future and the consequent responsibility which rests on the metallurgical industries for continued research, not only to meet demands which engineering is making for new materials, but for the provision of improved materials to stimulate this progress.

Unexplored Territory

A new industrial revolution almost unnoticed is in progress, pregnant with far-reaching results for the future. It is based on the almost daily discovery of new materials having new properties capable of standing increased stresses under all kinds of varying conditions of static or dynamic load within wide ranges of temperature. Lord Rutherford recently stated that: "It was now known that the tensile strength of a piece of steel was not much more than 1 per cent. of what it ought to be in a properly-designed and conducted world. The fault apparently lay with the presence of microscopic cracks in a crystal, and one could well imagine some genius coming along and showing how those cracks could be eliminated."

We only require to imagine the effect of increasing the present limits of tensile strength by two or three times to see that the design of our structures would undergo a complete revolution, and the stimulus to engineering invention might well produce results transcending our imaginative powers.

It is a matter for real gratification that every new discovery and achievement opens up an ever-wider horizon of unexplored territory. Thus the quest of the scientist and the engineer for further knowledge and achievement can never be ended. Thus the zest and sense of adventure remain and provide the greatest stimulus to progress. Metals are therefore much more than the material basis of the amenities of life, their development and application is continuously providing a stimulus to the intellectual growth of man.

WORLD'S PRODUCTION OF MORE IMPORTANT METALS.

Long tons (except Gold (oz.), Silver (oz.). and Quicksilver (lb.)).

	1900.	1929.	1933.	Ratio. 1929/1900.
Steel	28,300,000	118,300,000	66,700,000	4.2
Manganese ore	1,600,000	3,600,000	1,760,000	2.2
Chrome ore	40,000	590,000	278,000	14.8
Nickel	8,000 (est.)	55,000	45,300	6.9
Cobalt	100 (est.)	1,100	1,100	11.0
Tungsten (WO_3)	300 (est.)	9,400	6,600	31.3
Vanadium	1 (est.)	1,250 (est.)	100 (est.)	1,250.0
Molybdenum (MoS_2)	30	3,200 (est.)	4,800 (est.)	107.0
Copper	490,000	1,890,000	1,030,000	3.9
Lead	840,000	1,790,000	1,160,000	2.1
Zinc	470,000	1,140,000	990,000	2.4
Tin	95,000	189,000	96,000	2.0
Aluminium	7,500 (est.)	267,000	138,000	35.6
Antimony	7,500 (est.)	29,000	20,000	3.9
Gold (troy oz.)	12,400,000	19,400,000	25,000,000*	1.6
Silver (troy oz.)	174,000,000	265,000,000	171,000,000	1.5
Quicksilver (lbs.)	7,300,000	12,400,000	4,100,000	1.7

* Russian production estimated.

The Production of Iron—Ancient and Modern

At the conclusion of his lecture, Sir William exhibited a cinematograph film illustrating ancient and modern methods of producing iron. He was able to depict the ancient method by the courtesy of Mr. Harold Cookson (Past-President of the Staffordshire Iron and Steel Institute), who had brought the film from India. It was taken by Mr. Blundell, one of the managers of the Tata Company, who was living within 200 or 250 miles of a tribe the members of which were still making iron in the mediæval fashion. This iron craft, which was still practised in parts of India, West Africa and many other parts of the world, was a traditional tribal craft, handed on from generation to generation. In the process illustrated, the natives built a small superstructure of puddled clay, using elementary tuyeres and goat-skin bellows, the bellows being worked by various members of the family in turn, using their feet. The iron, which was extraordinarily pure, was produced in the form of a sponge. Each time the iron sponge was taken out of the furnace, the mouth of the latter was wrecked and had to be re-made. In a period of 12 hrs., from 15 to 30 lbs. of iron was produced. The film showed the lighting of the furnace by blowing in lighted charcoal. Ultimately the furnace was sealed at the top, except that a small hole was left to allow the draft to get out. The tapping hole for the slag was not permanent, but was made where it was wanted. The capital cost of the plant was 4 rupees, and Mr. Blundell had paid 15 rupees for the iron produced.

By the courtesy of many friends—the Brown-Firth Laboratories, Messrs. Lysaght and others —Sir William was able to show the section of film illustrating modern iron and steel smelting. A particularly attractive feature of the film was its excellent portrayal of the condition of molten steel inside a Héroult electric furnace.

PAPERS PRESENTED AT THE SHEFFIELD CONFERENCE

REFRACTORIES FOR FOUNDRY USE

By W. J. Rees, M.Sc. (Member)

Looking at the question quite simply, two general methods of lining the cupola must be recognised:—(1) The use of a brick lining and (2) the use of a rammed lining, some granular, plastic or semi-plastic material being rammed around a former. Consideration of the general characteristics of both types of lining, as well as the types of material used for maintenance purposes, such as patching material, will show that they all have individual characteristics.

In considering first of all the firebrick type of lining, and it must be remembered that even when the cupola is rammed with some type of lining it may have a backing of firebricks, there are a number of factors which are important in connection with their durability. Consider, for example, the general chemical composition of the bricks. Fig. 1 shows the alumina-silica fusion curve, and on it is marked the fusion point of representative firebricks. Particular attention is drawn to the general slope of the curve; as the proportion of alumina falls so the refractory value also falls. In other words, the higher the alumina content, the higher the melting point. Clays of comparatively low refractory value or fusion point, however, may have other characteristics which will render them of value for particular purposes.

In the modern cupola, very high temperatures are reached and a good deal of mechanical stress is prevalent, due to charging, slag action, etc., and it is desirable, therefore, to select a brick which will resist all these conditions as well as possible. It is quite evident from Fig. 1 that

from the point of view of resistance to high temperature the brick should be either high in alumina or high in silica. Unfortunately, the silica brick is not particularly suitable for the lining of the cupola because it will not satisfactorily resist very rapid heating or cooling. The cupola is of necessity heated up quickly, but quick heating is not desirable for the ordinary type of silica brick. A silica brick might be developed eventually which would withstand these rapid changes in temperature, but the present ordinary type of silica brick cannot be satisfactorily used in the cupola because of this lack of resistance to rapid heating and cooling. So from the point of view of refractoriness, the high-alumina types of firebrick must be considered; most firebrick manufacturers have such bricks in their range of products.

Cupola bricks, however, have to resist not only high temperature, but abrasion and mechanical stresses generally, and the question to be considered is whether the brick resistant to high temperature will be resistant also to these stresses. One characteristic of bricks made from fireclay is that they tend to lose some of their mechanical strength when raised to high temperatures, and the general trend is for this "refractoriness under load" to decrease slightly with increase in the alumina content of the fireclay.

Fig. 2 shows the results of "under-load" tests on firebricks used in cupolas, the load being 50 lbs. per sq. in. Marked differences are seen both in the temperature at which deformation commences and the rate at which it progresses. A general consideration of the mechanism of subsidence under load has shown that attention should be directed specially to the range A-B in Fig. 3. Below the temperature at which marked flattening of the curve becomes noticeable, point A, deformation occurring under loads occurring in cupola practice will be negligible. At temperatures higher than that corresponding to point B on the curve, severe deformation may take place under very small loads. Within the

range A-B, the rate and extent of the deformation will depend on the actual temperature and load; marked acceleration in the rate of deformation will occur with comparatively small increases in temperature. The iron-oxide content of a brick may have an important influence on its ability to withstand pressure at high temperatures in a reducing atmosphere.

The pressure on bricks in the cupola may be developed in three ways:—(*a*) From the direct weight of the structure; (*b*) from pressure developed by thermal expansion, and (*c*) from the weight of the charge. It is quite possible for these pressures to reach as much as 30 to 40 lbs. per sq. in. The desirable brick for cupola service, therefore, will be one which has a wide deformation range.

Glaze and Abrasion Resistance

Bricks made from clay having compositions in the region of comparatively low refractory value have the important characteristic of readily becoming skin-glazed, and become, in consequence, highly resistant to abrasion. Bricks in this category develop a "skin" when subjected to a temperature of, say, 1,400 deg. C., whereas bricks of a higher refractoriness would not.

Another important point is that of volume constancy during service. The general tendency of fireclays is to contract when raised to a high temperature. On the other hand, the tendency of silica is to expand. It is possible to produce a mixture of fireclay and silica in which the contraction of the fireclay more or less balances the expansion of the silica. Bricks of this "semi-silica" type are of value therefore under some conditions of service, despite their comparatively low refractory value. With all ordinary types of firebrick, the brick should be so thoroughly burned by its maker as to be free from permanent volume changes during service. Any marked "after-contraction" of bricks in the cupola will tend to reduce their durability as it will lead to opening of joints with consequent localised slag attack.

Black Cores in Bricks

Generally speaking, bricks of the high alumina type give much better service in a cupola, when the clay naturally contains just enough fluxing impurities to introduce vitrification without materially lowering the refractoriness. This vitrification gives mechanical strength to resist the severe abrasive conditions in the cupola. Uniform and thorough burning may be important from another viewpoint. Defective burning of bricks made from a carbonaceous fireclay may leave a black heart or core in the brick. The disadvantage of a black core is that it may lead to internal slagging of the brick. The clay contains 1-3 per cent. of iron oxide, and when this reacts with the clay under reducing conditions, the tendency is for the formation of ferrous silicate, which has both a low melting point and low viscosity and permeates through the brick, with serious detriment to its service.

Carbonaceous matter left in the core of the brick may produce reducing conditions inside the brick and so lead to reaction between the iron impurities and the rest of the brick, followed by slagging and rapid destruction of the brick. Too much stress cannot be laid upon the importance of careful burning. The general texture of the brick must be uniform and moderately fine to withstand abrasion.

Corrosion Resistance

Cupola bricks have to withstand corrosion by slags frequently high in both lime and iron oxide. The well-made and well-burnt fire-brick of the high alumina type will show more resistance to such slags than the siliceous type. It is useful to test the resistance of any particular brick to corrosion by the slag produced in any particular cupola. One method of doing this is to bore a hole in a brick and fill it with slag, subsequently heating to cupola temperature. After prolonged exposure the brick can be broken across the hole and examined for slag penetration. This method of test has the

effect, however, of destroying the skin of the brick which becauses of its density is more resistant to corrosion than the interior of the brick. A better method of test which retains this skin of the brick is to cement to the surface of the brick a ring made from a refractory clay, fill it with slag, and see what penetration takes place after heating for some time to the cupola temperature. Such tests give very useful data.

Close Jointing

It is very desirable that the cupola brick shall be so well made that it can be closely jointed. Close jointing always promotes durability and avoids the penetration of the joints by slag. Corrosion almost invariably starts at the joints, and the wider the joints, the quicker is the corrosion. Slag collects in the small "pockets," resulting in a rapid development of holes between the bricks.

Special attention should be given to the quality of the jointing cement, or mortar. It is little use taking a great deal of care in the selection of the bricks if an equal amount of care is not taken in the selection of the jointing cement. It might almost be suggested that even more care should be taken in the selection of the jointing cement. Jointing cements are now available which are even more refractory than the high-grade fireclay from which the bricks were made. Contraction in the jointing material may tend to rapid corrosion through opening of joints. The most satisfactory fireclay jointing cement is that which contains *a large proportion* of already burnt material, or grog, as this will show a much smaller contraction than a "neat" fireclay cement. The cement should also be very finely ground so as to keep the joints as thin as possible.

It is desirable to avoid bricks containing free-iron oxide, especially in a segregated form.

The cupola atmosphere may contain a high proportion of carbon monoxide, and when this comes in contact with free-iron oxide in the

bricks there is a tendency for the carbon monoxide to dissociate and carbon to be deposited. This may take place to such an extent as to cause actual disintegration of the firebrick. It will be seen, therefore, how important it is to avoid segregation of the iron impurities in the brick if this state of affairs is to be side-tracked.

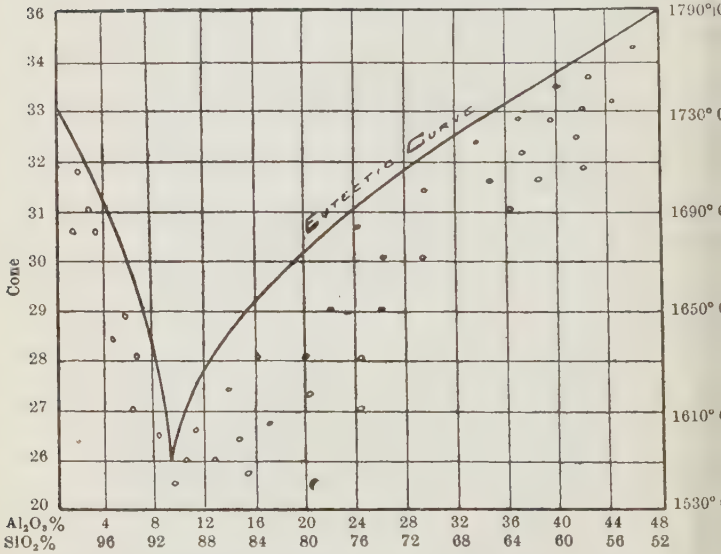

FIG. 1.—MELTING-POINT CURVE OF ALUMINA-SILICA MIXTURES.

Rammed Linings

There are a number of factors which are of great importance when considering the use of rammed linings. To give satisfactory behaviour in the cupola it is evident that the material must develop sufficient mechanical strength *on drying and heating* to resist the stresses set up.

When the rammed material is heated it must vitrify enough to produce mechanical strength and must have satisfactory volume stability, as

excessive shrinkage may lead to the opening of cracks.

Most of the mixtures which are used for ramming cupolas are in the highly-siliceous end of the curve (see Fig. 1), and will contain more than 90 per cent. of silica. They should not be in the region of, say, 88 to 90 per cent. silica, because that is the region of the lowest melting point. They should either be 1 to 3 per cent. higher, or 5 to 10 per cent. lower and not near the eutectic point. The presence of fluxing im-

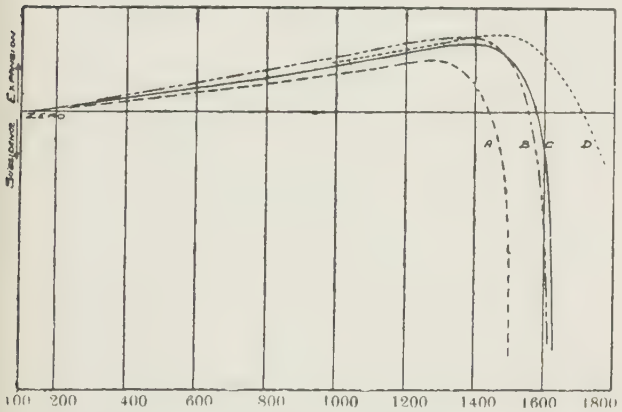

Fig. 2.—Under-Load Curve of Cupola Bricks.

purities in the material tends to move the eutectic to the right (Fig. 1).

In general practice the mixtures of this type are made from either a naturally-occurring highly-siliceous material, or from a mixture of a highly-siliceous rock, with just enough clay to give it the necessary workability, but whether a natural material or a synthetic mixture is used, it is desirable to keep well clear of the eutectic composition.

Fortunately there are excellent materials available which will give ramming mixtures having the correct characteristics, although most

of the natural materials may not be suitable for direct use without some preparation. With synthetic mixtures more control is possible, but a difficulty with such mixtures is to obtain such perfect distribution of the clay over the silica grains as is found in some natural deposits. It is particularly important that the producer working a naturally-bonded deposit should take great care to keep to a sample, and avoid variations in bond content or texture. It is possible to improve the characteristics of some of these naturally-bonded materials by making additions to them of crushed silica rock or high-silica sand.

Patching Materials

Patching materials, used for cupola lining maintenance, must have such characteristics as will enable them to "stay put," or develop adhesion, when heated. The wet patching material is forced into position, the worn place made good, and, almost immediately, the cupola heated. The following cycle takes place:—

(1) The water in the material driven off; (2) the combined water in the clay driven off and (3) sufficient vitrification is induced to make that patch adhere to the rest of the lining. It will be seen, therefore, that about as severe a condition as one can imagine is set up, so a material has to be selected that will withstand those severe strains, which is no easy matter. Such materials must be used always with only just enough water to give the necessary characteristics for patching. The patching material must not be over-watered, otherwise cracks will tend to develop, resulting in the penetration of slags.

Materials of this kind are generally made by mixing crushed high-silica rock—such as Sheffield ganister—with a refractory plastic clay. The very best type of silica rock should be used.

The materials known as "Cupola Ganister" are very mixed both in composition and texture, and whilst the producers of these materials in the Sheffield area have made great progress

in standardising this product, such standardisation is made difficult by the great variation in cupola conditions. It is by no means unusual for a ganister mixture which gives good service in one cupola to be totally unsatisfactory in another working under conditions which do not appear to be very dissimilar. It seems evident therefore that the method of using the ganister has a definite influence on its durability. Incidentally, a ganister patching would often last better if more care were taken in the

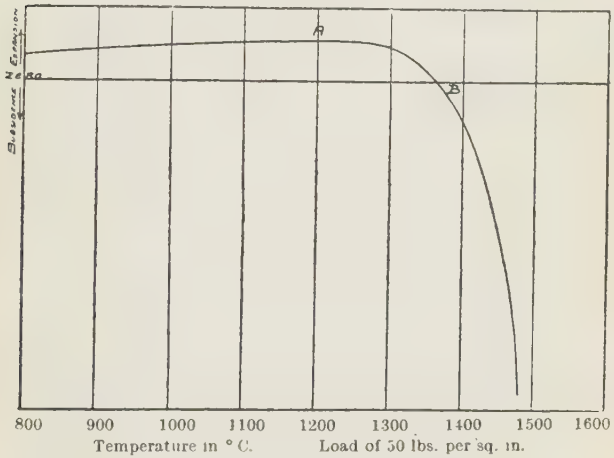

Fig. 3.—Under-Load Curve of Firebrick.

cleaning and removal of clay from the worn place in the cupola.

It is not an easy matter to produce a material which will withstand the strains which are set up in the normal usage of cupola ganister. The water content should be only just sufficient to give the necessary workability to the material, as over-wetness whilst it may make patching easier will reduce the mechanical strength of the patch and lead to cracking and consequent slag penetration, despite the expansion which takes place when the silica rock becomes hot. As a

basis for these materials it is desirable to use a silica rock, such as the typical Sheffield ganister, which crushes into angular fragments. Rounded fragments tend to slip over each other, and so lead to weakness, whilst angular fragments tend to interlock and so promote strength. It is important that the matrix of the cupola ganister (*i.e.*, the finer fragments of silica plus the bond clay) should have a composition which is not too near the eutectic (Fig. 1), as this will lead to rapid fusion and possible dripping or running out of the matrix and a "honeycomb" type of corrosion or wear. A useful method for testing a cupola ganister is to slowly heat briquettes (say 4 in. by $1\frac{1}{2}$ in. by 1 in.) made from an average sample to 1,500 deg. C. and hold them at that temperature for 5 or 6 hrs. A good material will show little or no shrinkage, and will be well vitrified with only slight deformation of shape of the test-piece and no "running-out" of the matrix.

DISCUSSION

Mr. V. C. Faulkner (Past-President) said that Mr. Rees had stressed the necessity for dimensional accuracy, but like others he usually pointed out in the phrase immediately following the importance of using a minimum amount of cement. Another feature to be borne in mind, however, was the convexity of the surface; if there were a convex surface a good deal of pressure was applied locally, which would reduce the melting point of the brick.

Another factor was that in the early life of any furnace structure there was a vast amount of erosion and corrosion; but, after the thickness of a wall was reduced, say, from 9 in. to $4\frac{1}{2}$ in., it would "stay put" for a long time. That phenomenon was obviously connected with the heat conductivity and the cooling effect upon the refractories, and Mr. Faulkner drew attention to this point so that it might be taken care of in research, with the object of determining, prior to the construction of the furnace, the most desirable thickness of the wall.

Finally, he asked if Mr. Rees had had much experience of painting walls immediately after construction in order to induce a glaze very quickly.

Blast-Furnace Linings

Mr. F. S. Russell expressed great indebtedness to Mr. Rees for his Paper, which was as able a contribution and as full of insight as all contributions he had made towards their knowledge of metallurgical and refractory problems.

With regard to blast-furnace linings, which subject had received a great deal of consideration in recent years, Mr. Russell pointed to the modern movement in favour of high-alumina bricks—bricks containing more than 40 per cent. of alumina. He asked if Mr. Rees would say whether he considered that that movement was likely to go further—whether it was likely, for instance, that a brick containing 45 per cent. alumina would give better results than one containing 40 per cent., whether a brick containing 48 per cent. would be better than one containing 45 per cent., and so on. Was there any real sound basic reason for this preference for high-alumina brick in blast-furnace linings, or was it merely based on the theory that the higher the alumina content, the higher the refractoriness of the brick?

He also asked whether it was part of the theory that high-alumina bricks in a blast-furnace lining resisted decomposing agents better than would an ordinary fire-clay brick containing perhaps 34 or 35 per cent. of alumina.

Jointing Cements

It was pleasing to note that the problem of jointing cements had received special mention in the Paper. All who were concerned with furnaces and kilns had had experience of the failure of bricks because of the way in which the bricks were bonded during building. Very occasionally it was due to the refractory (laughter), but Mr. Russell felt sure that in

most cases the greater part of the trouble could be traced to the jointing cement. People held loose ideas with regard to jointing cement. He had seen expensive silica bricks, carefully made, fully converted, fully of tridymite and crystabolite, put together with joints more than half-an-inch thick in which was used a cement consisting to the extent of about 50 per cent. of a very ordinary fire-clay, the other 50 per cent. consisting of old silica bricks ground up, a little sand being added. Of course, a nice fat, sticky cement like that would work a great deal more easily on the trowel than would a really high-class refractory silica cement, and there was no doubt that even now, despite the advance of scientific knowledge, far too much latitude was allowed the bricklayer in regard to the cement he used with expensive firebricks. Mr. Russell said he had also seen a brick kiln, which was to work at a high temperature, being built of fire-clay bricks, the cement for the jointing of which was made in his presence and consisted of at least 25 per cent. of ordinary mortar. After a while, of course, the joints began to weep, the droppings from a joint would run down the face of the brick below it, and melt that brick, and formed with that brick a mixture which helped to melt the next brick. That state of affairs continued until all the surface had become glazed, then sooner or later, the joints were hollowed, so that the destructive gases and dusts got into them, undercut the bricks and reduced their life by about 50 per cent. As a result of this sort of thing, the firebrick manufacturer was blamed, and only because he had not had the opportunity of checking up the material used with his bricks in the construction.

Ground Ganister

Mr. Russell said that one never heard a solitary voice raised about ground ganister during the course of all the mass of research work, despite the fact that so many Papers were produced dealing with such kindred subjects as "Silica Bricks" and "The Classification and

Testing of Sands." It seemed to him that ground ganister, which was the commonest refractory of all, and was a term that covered a multitude of sins, received the least scientific attention of any refractory known to industry. So much depended on ground ganister, that it was high time that people realised they could not buy any kind of common rubbish and yet obtain good results. It was the custom in some places, though not in the Sheffield area, to make ground ganister out of material which was not good enough for silica brick making. Such a mixture, though cheap, was unsatisfactory, and people must not complain if they did not secure good results from it. His experience, supported by that of Mr. Rees, was that perhaps the most important feature of a good ground ganister was the particular type of clay used in its production. Not only must that clay be highly refractory, but it must be very sticky, so that as little as possible of it could be used to give the desired result. But all the clays which possessed those two virtues were expensive; so that it was really impossible to produce a high-class, reliable and successful ground ganister at other than a reasonable price.

Carbon Deposition

Professor Thomas Turner (Emeritus Professor of Metallurgy, Birmingham University) was glad to have the opportunity of commenting upon the Paper by his old friend Mr. Rees, who was in Birmingham for a number of years, where he had always been very helpful and friendly.

With regard to the problem of carbon deposition, which occurred in the cooler parts of the cupola, and was sometimes noted very much in blast-furnace work, if by any oversight one used refractories in which there was a quantity of oxide of iron, Professor Turner said it was astonishing how much carbon could be deposited in those circumstances. A little globule of iron was reduced and it continued to act upon carbon monoxide so that more and more carbon was deposited until, if the process were allowed to

proceed, the carbon became very much more bulky than the original brick on which it had been deposited. That was an extreme case, of course, but it had occurred not infrequently within his own practical knowledge.

Discussing the important question of the strength of a refractory at its higher working temperature, he said one might have two refractories, one of which would be regarded as of inferior quality, but at a high temperature it would withstand greater pressure and more knocking about from the charge than would the one of higher quality. It was a question of the toughness of the refractory at high temperature, so that, as Mr. Rees had pointed out, it might be an advantage in some cases to have a refractory giving a lower cone temperature but which at the same time would be more effective in practice.

Case of Over-Insulation

With regard to the lagging of the furnace, to prevent heat loss, he recalled Mr. Faulkner's reference to bricks becoming gradually eaten away inside the furnace until their thickness was reduced to perhaps half the original thickness. If that process were continued indefinitely, of course, the bricks would wear until the outside of the furnace was reached, and relining would be necessary. But there came a stage at which outside lagging might not be economical. Several cases had been brought to his notice in which it had been found more economical to lose a little heat than to reduce the outside losses, because by reason of the lagging the firebricks inside had melted more quickly, so that the furnace had to be relined earlier, involving more frequent interference with its operation. It paid better to lose a little heat than to lose the firebricks. Ultimately, of course, it was a question of balance, and a question of economy; but external cooling of a furnace was sometimes more important than the actual chemical composition of the material used for lining it.

Refractory Cements

Discussing the cement used between the bricks, he said that as a general rule the less cement one could use, the better. But if a cement had to be used, it should be of the highest quality. He recalled having been consulted some years ago at a works at which considerable trouble had been experienced. The works were rolling good material—a special quality wrought iron—and in the rods that were rolled there were inclusions of a material the colour of which was nearly white, but it obviously was non-metallic, something in the nature of a white slag. They could not trace this trouble. When he had looked into the re-heating furnace he had seen tears form on the roof and drop down upon the piles of material that were to be rolled, so that they were rolled into the material and had spoiled it for the purpose for which it was intended. He had inquired what clay had been used for the jointing and was told that they had some very good local clay, samples of which they had shown him. He had examined it and had found that although it looked very much like fire-clay it was not fire-clay at all, but was the commonest material. That was only one illustration within his experience of how considerable expense and trouble were involved due to attempting false economy. There was no doubt that if one were to build good structures of fire-clay materials, such jointing as was necessary should be made of material at least as good as that of the bricks themselves.

Mr. J. H. Cooper, having expressed his appreciation of Mr. Rees' valuable Paper, said its usefulness would be increased if Mr. Rees would warn people using refractories concerning the amount of limestone which would enable them to secure a really better life from a refractory. Also, did he consider it possible, for example, to use in the cupola a portion of monolithic lining and a portion of brick lining, because one expanded and the other contracted, and by means of such a combination one might avoid difficulties with the joints?

Author's Reply

Mr. Rees replied to the discussion. Dealing first with the important question raised by Mr. Faulkner concerning the thickness of the wall, he said that in some industries it had actually been found to be beneficial to start with a thinner wall, it having been found that the thinner wall lasted just as long as the original thick wall had done.

It was pleasing also that Prof. Turner had contributed to the discussion, for he had been responsible for the enthusiasm of a good many of those working in Birmingham in earlier years. It had been their practice to go to him with many of their troubles, and such success as some of them had achieved had been due in no small measure to the encouragement he had given them at Birmingham twenty or thirty years ago.

The point raised by Mr. Cooper concerning the possible use of a combination of a monolithic and a brick lining was exceedingly important, and Mr. Rees believed that very definite progress could be made by the proper utilisation of such combinations.

Written Communication

Mr. G. W. Brown wrote:—The author of the Paper was to be highly commended for putting the matter in such a practical form, and one that could be read and digested with profit by even the man who put on the daubing. It was a subject in which the foundry could do with all the assistance from universities and laboratories obtainable, and in such a practical manner as the present Paper.

The writer would be grateful for a little more enlightenment on the possibility of disintegration through the charging, whether there was likely to be any appreciable difference between the hand and mechanical charging? Also did the shape of the cupola lining, *i.e.*, either straight lined or conical lined, have any effect on the mechanical stress as mentioned?

The author also spoke of the cupola as being heated up quickly. Could he translate this into

time, as the writer endeavours to prolong this time to the maximum by keeping a slow fire going all through the night in the cupola to be used the following morning? The emphasis placed on the close jointing is of great importance.

Would it not be possible to arrive at some standard, particularly in the moisture content of the material used for patching, as the life of the lining would appear to be not so much due to the quality of the bricks as the quality of the daily patch in the melting zone and the methods of application?

Author's Written Reply

It is difficult to express an opinion as to the relative effects of hand and mechanical charging without close examination of particular cupolas, but, generally speaking, the greater uniformity with mechanical charging is likely to be advantageous to lining life. The stresses developed on heating will certainly vary with the shape and thickness of the lining, but it is not likely that the differences between straight and conical lining will make much difference to the stress developed in any particular material.

It is obvious that practical considerations will limit the time which can be taken for the heating-up of the cupola, and Mr. Brown's practice probably represents the best which can be done. With siliceous lining materials there is no doubt that a very slow rate of heating up to 600 deg. C. is advantageous; it is desirable also that direct impingement of flame on the "cold" lining should be avoided, as this is likely to cause a localised rapid rise in temperature.

It is certainly desirable to endeavour to standardise the characteristics of lining and patching materials, and with the latter the uniformity of moisture content is especially important.

SAND PROBLEMS IN A BRASS FOUNDRY

By F. Howitt

The past few years have witnessed an increasingly insistent demand for a higher level of quality in brass castings. With the rapid development of the hot-forging process and the consequent competition, new standards of comparison have been set up, and the resources of the foundry have been heavily taxed in the effort to realise them. This applies not only to the brasses, but to the gunmetals and bronzes also, for in many cases stamped brass has been substituted for these alloys, and is now used by engineers, and, more significant, appears in engineering specifications for purposes where gunmetal and bronze, formerly, were used exclusively.

The extended use of electro-plating, more particularly chromium plating, has also had a pronounced effect in creating a demand for castings of higher quality, for it is a fact that the high polish necessary for these processes renders very small surface defects easily visible. It is here that stamped articles score heavily, because the nature of the process ensures that the surface shall be free from such blemishes, whereas that of sand castings is never free from embedded particles of sand, or possibly minute cavities formed during solidification by the liberation of gas absorbed in melting.

It is probable that the efficiency and reliability of the casting process is, in general, much less than that of the other major fabricating processes. There are many reasons for this, but chief among them is the lack of fundamental knowledge. On this account the brass foundry is in a poor position to defend itself against the inroads made by the newer, more scientific processes, and the position is likely to become more acute in the future. There is, in brass foundries, a great wealth of empirical knowledge,

much of it authentic, but a quantity of it is based on misunderstanding of the phenomena involved, most of it is confused and uncertain and little is co-ordinated or even recorded.

Fundamental Knowledge Lacking

The laws which govern the successful manufacture of castings are only superficially known or vaguely suspected. Compared with the other branches of metallurgy development in this field has taken place at a relatively slow rate. There is a definite reason for this, for where there are many contributory factors, as there are in the manufacture of castings, and each is apparently subject to spontaneous variation, the isolation of any one in order to determine its significance is extremely difficult. In these circumstances, one is compelled to regard the results of direct experiment with suspicion.

The degree of uncertainty and the seeming contradictions which attend the making of brass castings are a direct result of these variations, and the author desires, in this Paper, to give an account of some methods which may be adopted to reduce them to reasonable proportions.

If castings be subjected to tests which determine their relative soundness, such as hydraulic pressure or polishing tests, it is found that some are good, some bad, and some are indifferent. Clearly, then, there are variations in the process which operate obscurely, and they occur not only between one batch and another, nor between one mould and another, but between individual castings in the same mould.

Sand—the Cardinal Consideration

Further, if the unsound castings be dissected, and the defects examined, provided that primary precautions have been taken in the melting and casting, it is found that easily the largest number of defects is caused, directly or indirectly, by sand. This is determined by the actual presence of sand in the defects, which is not revealed, in most cases, until it is examined under a moderate power microscope. This sand finds its way into the casting by various ways,

and may come from either the core or the mould. Its presence in some cases and absence in others, and the many forms in which it is manifest, are a sure indication of the variable character of the medium and its manipulation.

Certainly the most inconsistent of all the materials met with which the foundry has to deal is moulding sand. It is of a complex nature, consisting essentially of sand grains proper, clay or other colloidal matter and moisture. All of these are liable to vary, and therefore to affect the properties of the sand.

Variations in moisture, for instance, produce variations in cohesion and plasticity, so that under a given load, which is the condition prevailing in machine moulding, the sand will ram more or less densely. This produces corresponding changes in the permeability and the strength.

Influence of Moisture Content on Bunter Sand

In a certain moulding sand, for example, drawn from the Red Bunter deposits, the writer observed that an increase from 5.5 to 6.0 per cent. in moisture produced an increase from 1.61 to 1.68 in density. At the same time the permeability fell from a value corresponding to 22.5 on the A.F.A. scale to 19.5, whilst the green strength increased from 375 grams per sq. cm. to 410 grams per sq. cm. In another sand treated in the same manner, the density rose from 1.57 to 1.66 and the accompanying changes in permeability and green strength were from 26 to 22.5 and 350 grams per sq. cm. to 386 grams per sq. cm. respectively. Both these sands had to be worked with the moisture content as near to 5.5 per cent. as possible. Below 5 per cent. the cohesion was insufficient to give a good "lift." Above 6 per cent. trouble was experienced from minute blows, which gave rise to subcutaneous defects, and these prevented a high finish being obtained. Behaviour of this kind is common to the Bunter sands, at least, and is quite liable to spoil castings, particularly when such castings are to be chromium plated.

It is, in general, necessary to control the moisture to within a minimum of at least 1 per cent. and this is not easily accomplished. The moisture in the new sand is rarely consistent; that in the spent sand is still less and the amount lost by evaporation in the milling process will vary enormously according to the conditions prevailing, such as atmospheric temperature and humidity, etc.

For instance, it was found that if a heap of sand was allowed to collect under the aerator, differences as much as 0.5 per cent. moisture could be obtained between the top and bottom of the heap. This was due to the difference in distance traversed; the further the sand was thrown the more moisture it lost.

Moisture Control

The control here took the form of an electrical moisture indicator arranged so that determinations could be made in a few seconds. Samples from the aerator are tested every few minutes and the water addition is adjusted accordingly. It is found that the moisture content can be controlled to within 0.5 per cent. The readings on the indicator are quite arbitrary, but with the same sand and water supply this is immaterial.

The clayey matter in a moulding sand can vary in both quality and quantity. The more finely divided or colloidal it is the greater will be its strength, and therefore the state of subdivision is of great importance. Unfortunately, the ferruginous bonds of the Bunter sands are not very highly colloidal and often contain a large amount of silt. The character of the bond, however, appears to be fairly constant in the same sand, but the quantity can, and does, vary.

This leads to variation in the strength of the sand and to the optimum moisture content which can be rectified by admixing more or less new sand. It is not, therefore, very serious where an adequate system of testing is maintained, but it also leads to minor complications in the mixing and milling process, where a larger quantity of

new sand must be allowed a longer time to become thoroughly incorporated. This, necessarily, slows down the production of a batch system of sand preparation, but does not have that effect on a continuous system. In the latter case, arrangement is made for the sand to dwell longer under the rollers.

So far as the author has been able to determine by microscopic observation, there is little difference in grain shape in sand from a given source. There may, however, be considerable variation in grain size. Differences in grain size, of course, produce changes in permeability and strength. A smaller grain size will give lower permeability and, with the same milling and bond conditions, a finer sand will possess lower strength. Consequently variation in grain size may easily produce considerable variation in the properties of the sand.

Variation in Grain Size

From a series of physical analyses of sand from a certain source the author found that the grain size altered considerably, and did indeed result in fairly large differences in the properties of the sand. A number of the results of these analyses are reproduced in Fig. 1. This is part of a chart compiled from the analyses, but slightly modified to avoid complexity. The one set of ordinates refers to percentage weight of the different constituents whilst the other set is quite arbitrary and refers to successive consignments of new sand.

It will be seen that the moisture varies from 8 to 16 per cent., whilst the quantity of bond varies from 10 to 15 per cent., facts which are very disconcerting even when adequate provision is made for tests on the sand in use. Such extreme variation in moisture may well have the effect of placing either the moisture or bond beyond control. It is, moreover, fairly typical of any open-worked fluvio-glacial sand and a large exposure of the workings to the weather will obviously produce great differences in the moisture.

The sand grains themselves have been classified under two heads, namely, those greater and those less than 0.006 in. From the chart, they are seen to vary enormously and the reason for the inconsistencies before mentioned is apparent. The sands containing most of the coarse constituent are of higher permeability; those containing most of the finer constituent are of lower

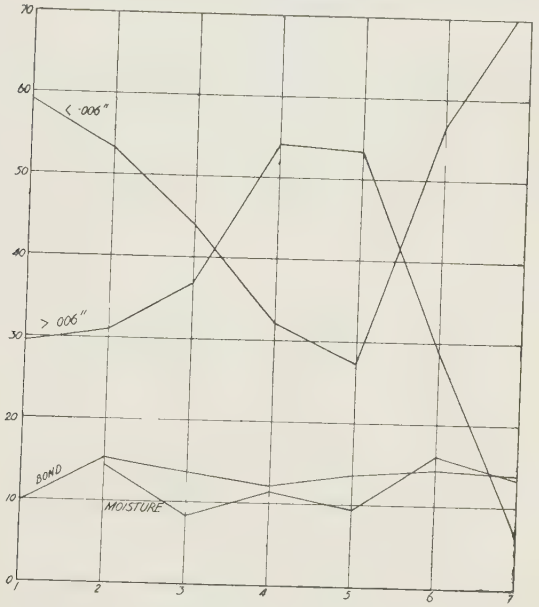

FIG. 1.—SHOWING VARIATION OF GRAIN SIZE IN SUCCESSIVE DELIVERIES OF NEW SAND.

permeability. The alteration, calculated to agree with the A.F.A. scale was from 31 in the No. 5 sample to 20.5 in the No. 7 sample. The measurements were made on specimens arranged to contain 5 per cent. moisture and were rammed under a load of 2.6 kg. per sq. cm., which is the pressure at which the moulding machines operate.

Recording Grain Size

In order to obtain a clear idea of the distribution of the different grain sizes, individual curves were plotted for all the sands under examination. A number of them are reproduced in Figs. 2 to 12. Since they differ from the ordinary cumulative curves it is necessary to explain their construction.

In the first place, ordinates are set out at distances from the zero to correspond with the apertures of the sieves used in grading the sample. These distances are arranged on a linear scale of thousandths of an inch instead of the rather meaningless denominational scale sometimes adopted. Those used here are 2.1, 3.0, 4.0, 5.1, 6.5 and 10.4 thousandths of an inch respectively. An ordinate is also drawn, tentatively at 0.001

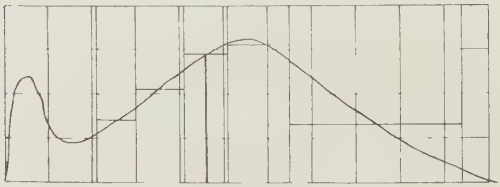

Fig. 2.—Mean Grain Size 4.6.

in., to indicate the limit of the clay constituent. Its exact position is unimportant to the purpose of the diagram.

The weight of sand which remains between each pair of sieves is then divided by the difference between them. This gives the weight of sand per thousandth/inch for each pair and a horizontal line is drawn between the corresponding ordinates at a height proportional to this ratio. The area bounded by the horizontal line and the ordinate on either side is then proportional to the weight of sand remaining between the particular pair of sieves. In this way a connected series of lines is obtained throughout the range of the sand. These occur at greater or lesser heights which clearly show the occurrence of maximum and minimum points in the distri-

bution of the grains. The regular curve is then drawn, which passes through these maxima and minima, in such a manner that the area contained between the curve and any pair of ordinates is the same as that between the ordinates and the horizontal line. Under this condition a strikingly accurate curve can be obtained. The whole area bounded by the curve is proportional to the total percentage of sand.

Interpretation of Curves

This curve has a definite mathematical significance. Its height at any point is the differential

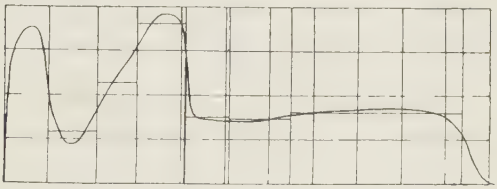

Fig. 3.—Mean Grain Size 4.1.

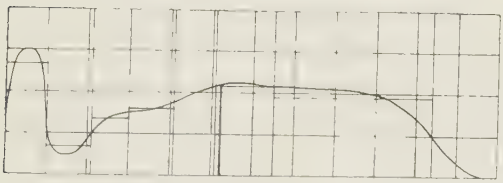

Fig. 4.—Mean Grain Size 5.2.

coefficient of weight of uniform grains per thousandth of an inch and it can be made to give the information associated with a differential curve. Its slope, for instance, indicates the rate of change from one grain size to another.

Its value lies, chiefly, in the fact that it provides a true picture of the constitution of the sand. It shows the way in which the dominant grain sizes are disposed, how many dominant grain sizes there are and their relation to each other. It is, moreover, independent of the actual

sizes of sieves used. No matter what series of ordinates is adopted, the same curve would be obtained provided that the same range were adequately covered. This makes the correlation of results an easy matter, for results from one source are strictly comparable with those from another, which is a highly desirable circumstance unattainable merely by comparison of results of analysis or cumulative curves.

A figure is given with the diagram for each sand for the mean grain size and its position relative to the curve is fixed by a thick vertical line. This was obtained by the method first published, the writer thinks, by Primrose and attributed to Scott. It was subsequently adopted by the A.F.A. It has here been modified from the irrational denominational scale to the linear

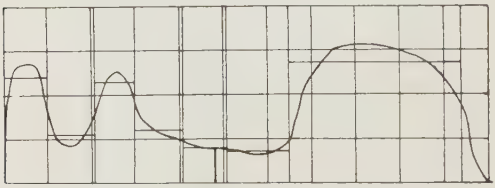

Fig. 5.—Mean Grain Size 4.8.

scale and the figures are given in thousandths of an inch.

Figs. 2 to 7 are the diagrams for the series of sands shown in Fig. 1. It will be observed that they are vastly different in character. The mean grain size fluctuates from 4.1 to 5.2 and occurs sometimes near a maximum point as in Fig. 2, but mostly near to the minimum. This means that the sands contain comparatively few grains of their mean grain size, a circumstance which is undesirable in a moulding sand. Incidentally, this can be quantitatively estimated from the diagram.

Further, with one, or possibly two, exceptions this series shows two maximum points, which clearly indicates that the samples are mixtures of two sands of markedly different grain size.

These vary in quantity with respect to each other throughout the series, thereby producing the difference in properties before mentioned.

Examination at the Quarry

With a view to reducing or possibly eliminating this dual character of the sand, the bed from which it is derived was examined. It was seen to consist of several seams, apparently similar in

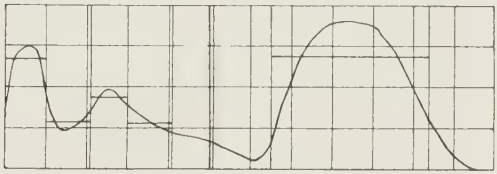

FIG. 6.—MEAN GRAIN SIZE 5.05.

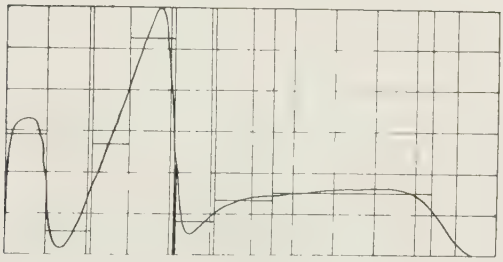

FIG. 7.—MEAN GRAIN SIZE 4.15. THE DIAGRAM FOR NO. 6 SAMPLE IN FIG. 1 IS SIMILAR TO THE ABOVE, AND IS THEREFORE NOT REPRODUCED.

character. Samples were taken from each of these seams separately, and each sample was duplicated some distance away from the original point. The object in doing this was not only to ascertain the precise differences between the seams, but also to form an idea of the possible variation within them. It is unnecessary to the purpose of this Paper to reproduce all the results

of the examination of these samples. Three only are given, Figs. 13, 14 and 15. Fig. 13 is the diagram of the seam which was finally adopted. Figs. 14 and 15 are those of other seams from the same bed. Suffice it to say that the individual seams were very dissimilar in character and the diagrams 13, 14 and 15 are merely typical. Moreover, they appear to be fairly typical of the dissimilarity which may exist between juxtaposed seams anywhere in the Bunter system.

The variation within the seams appeared to be comparatively small. Some seams were better than others in this respect, but the extreme difference found was probably no more than could be expected from a sand formed under fluvio-

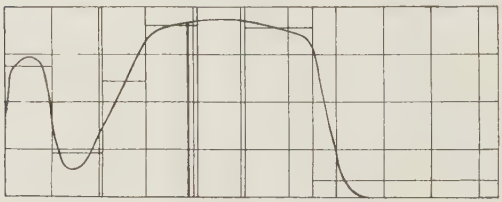

Fig. 8.—Mean Grain Size 3.87.

glacial conditions. This has been confirmed by comparison with sands drawn from other sources. It appears, moreover, to be of little importance from the practical standpoint.

Basic Dual Character

The most striking fact in connection with the examination is that the dual character of the sands is evident in each seam of sand. This means that it is not produced by adventitious mixing of dissimilar seams, though this may serve to emphasise it, but it is an inherent characteristic.

That this is a fact has been verified by examination of sands from other sources. Samples have been obtained from widely different points in Nottinghamshire and Yorkshire and

upon examination, have, with one exception, revealed the same characteristics, namely, that they are mixtures of two or more sands. Rarely are there more than two. The author has met with only one sand which shows three maxima and has never seen one with more. With regard to the exception mentioned above, this is definitely a single sand and approximates to the fine constituent of the dual sands. It was probably formed under abnormal conditions during the early part of the glacial period and there is, moreover, very little to be found.

Fig. 13 is the characteristic of the seam from which it was decided to draw supplies for use.

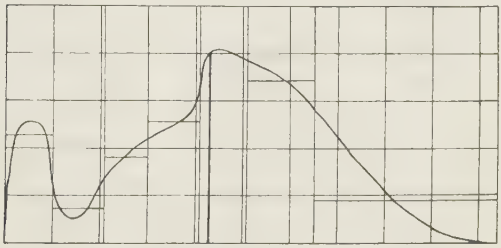

FIG. 9.—MEAN GRAIN SIZE 3.96.

The choice was made for definite reasons, quite apart from the fact that the bond was satisfactory and the grain size adequate. It will be seen from the curve that, in common with the other sands, this also consists of two maxima. But in this case they have moved closer together so that they merge into a single rather broad maximum. It is obvious that if, for any reason, the respective amounts of the two dominant grains were to vary, it would produce less difference in the mean grain size than would occur if the dominant grains were very dissimilar. That such fluctuations were probable is shown by the curves Figs. 2 to 7, where the main differences are the respective amounts of the two chief grain sizes. It was thought that in this way some measure of consistency could be obtained, since it was quite clear that the variation in

grain size was responsible for the inconsistencies experienced in the strength and permeability of the sand in use. Moreover, in such a sand where the minimum point is suppressed, there would be the highest number of grains of mean grain size.

Behaviour of Controlled Sand Supply

This view was amply substantiated by subsequent experience. Figs. 8 to 12 are typical diagrams of the sand received after the examination of the bed. It will be seen that they are similar in form, but that the two maxima vary as expected. Despite this, the mean grain size varies only from 3.75 to 4.32 $\times$ 10^{-4} in., and that over a period of about five months the permeability became constant between 22 and 26 and the green strength varied only between 350

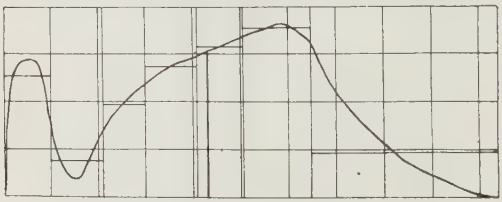

Fig. 10.—Mean Grain Size 4.32.

and 400 grms. per cm^2. Altogether, a fair degree of reliability was obtained and this was reflected in better achievement in the foundry.

Subsequently it was ascertained that the overlapping of the two maxima is a characteristic of the more famous moulding sands, although these are not necessarily suitable for every purpose.

Core Sands

The question of the suitability of a sand for a given purpose appears to be a very open one. The only determinate method seems to be the choice of a suitable grain size by experience or usage, and then to find the highest quality sand which approaches it. This problem applies, also, to sands for coremaking, and possibly to a larger degree, despite the fact that the extended use of bondless oil-sands has done much to

eliminate the uncertainties attached to this operation. There are cases where it is impracticable to use bondless oil-sand for economic reasons, and in such cases it is still customary in brass-foundries to use spent moulding sand for cores.

This practice is unsatisfactory, since sands which are suitable for use under the low gas-pressure conditions which exist in the mould are unsuited to the high-pressure conditions which prevail in the core. Moulding sands for brass are necessarily of fine grain, and therefore of low basic permeability. High permeability is required in cores so that the gas formed during casting may be evacuated at a sufficiently low pressure. Further, the bond in the black sand consists of that proportion of clay and starch or other organic binder which remain from the previous casting operation, and is therefore small. It is not easy to supplement them. Additions of clay reduce the permeability still further and make the core difficult to remove from the casting, whilst additions of organic binder increase the gas evolved. Hence it is necessary to increase the permeability of the sand in some manner, and this is usually accomplished by light ramming.

These two conditions, low bond and light ramming, result in cores which are physically weak and variable in character. They need careful handling to avoid breakage and, on account of their low cohesive strength, almost invariably shed sand into the mould whilst being laid.

The author examined a large number of such cores with an instrument constructed to measure the permeability in the actual cores. This revealed differences in similar cores, which precluded the possibility of good castings being made with them all. Those of higher permeability than the average were physically weak and liable to erode or collapse under the impact of the metal stream. Those of lower permeability, whilst being stronger, showed a marked tendency to blow.

Overcoming Core Troubles

An attempt was made to increase the permeability by mixing coarser sand with the black sand, and making an addition of liquid binder. This proved only partially successful for several reasons, the chief one being the absorption of moisture by the baked cores on account of the type of binder employed.

The idea was then formed of a sand which could not be rammed too hard. When sand is rammed under a gradually increasing load there is a gradual decrease in permeability, and a gradual increase in both green and dry strengths. These changes are not proportional to the load applied, but increase rapidly at first, and then die away until finally a large increase in the applied force produces no change in the physical properties of the rammed sand. At this point the grains of sand are in close contact, and obviously until the pressure reaches that necessary to rupture the sand grains themselves no further change is possible. This latter force is many times greater than that required to produce complete compression, and it happens, therefore, that for all sands there is a range of pressure within which variation in the ramming load produces no change in permeability and strength.

The minimum of this range of pressure depends upon the type of sand employed, being less for coarse sands than for fine; less for rounded grains than for angular grains; and less for sands containing an oil binder than for those in which a clay binder is used. For instance, with dry sand containing no binder, no external pressure is required to bring the grains into close contact. With the bondless oil-sands very low pressure, about 1 lb. per sq. in., is sufficient, and with the plastic dextrin-oil sands pressures of about 5 to 15 lbs. per sq. in. are required, whilst with the fine, angular grain moulding sands containing large amounts of clay, pressures of 80 to 200 lbs. per sq. in., according to the plasticity of the sand, are usually adequate.

Fully Compressed Sands

In the fully-compressed state, a sand develops its minimum permeability, and it is necessary, therefore, to select a sand in which the grains are sufficiently large and regular in size. At the same time, it develops its maximum green and dry strengths, and is therefore more able to withstand the stresses to which it is subjected in use, such as the erosive effect of a stream of molten metal, which is a frequent cause of losses in a brass foundry. More important, however, a sand fully compressed is very consistent in behaviour, being of equal hardness throughout its mass. The desirability of this condition will be appreciated when it is remembered that few moulds rammed on even modern moulding

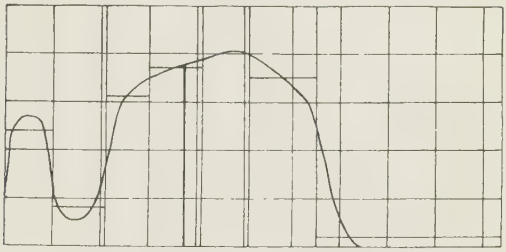

Fig. 11.—Mean Grain Size 3.75.

machines are equally hard over the whole face or from face to back. They are usually harder towards the centre of the face and softer towards the edges, so that the middle of the mould will tend to blow whilst the edges may give way under the hydrostatic pressure of the metal and the mould "lift." There is a similar variation from the face to the back or *vice versa*, according to the direction of the ramming pressure.

It has not yet, however, been found possible to apply this principle to moulding, largely owing to lack of a suitable sand, but it proved very successful when applied to coremaking. A rounded-grain sea sand was first selected, having a mean grain size of about 0.009 in. and a base

permeability of 107 according to the A.F.A. scale. Later, in certain cases, it was mixed with a sand having a mean grain size of 0.005 in. and a base permeability of 50 A.F.A. This was found necessary because some larger cores gave a rough surface to the interior of the casting, due to the fact that, with large ports, the gas pressure developed inside the core was insufficient to prevent the metal from entering the interstices between the sand grains. By using a mixture of the two sands, this could be avoided and the permeability adjusted to any desired value between the two extremes. Later still, it was found possible actually to calculate the permeability necessary to prevent a given core blowing on the one hand and leaving a rough surface on the other. The method is herewith.

Selection of a Binder

The selection of a binder proved to be difficult. Some dozens were tested before a satisfactory solution was found, and then only by compromise. The organic binders, without exception, gave too low a green bond. These cores, as in most brass foundries, are required to retain their shape with no more support than is afforded by a thin wire passed through their centre. Most of them are of intricate shape and overhang considerably in whatever position they are placed, so that high green strength and rigidity are required in order to avoid distortion. The one great virtue of black sand, which compensates to some extent for its deficiencies in other respects, is its enormous rigidity in the green state, and this is a property with which it is impossible to dispense in cores which cannot be supported at their extremities.

It was eventually attained by using a mixture of bentonite and a dextrin-oil binder. With bentonite the green strength could be adjusted to whatever value was necessary, but used in excess it resulted in a serious decrease in the dry strength, due to absorption of the oil. A

dextrin-oil binder was chosen because it contributes a certain amount of green strength, and therefore the amount of bentonite could be kept to the minimum. In this connection it is interesting to note that one serious disadvantage of the dextrin-oil binders disappears. As is well known, when using these binders alone, the moisture content of the sand must be kept very low, to less than 0.5 per cent. in fact, in order to develop green bond. This moisture evaporates quickly so that the working range is very short. But on the addition of about 1.5 per cent. bentonite, the moisture content can be raised to 3 or 4 per cent. and the sand remains workable at 1.5 per cent. Moreover, on account of the high absorptive property of bentonite, the moisture

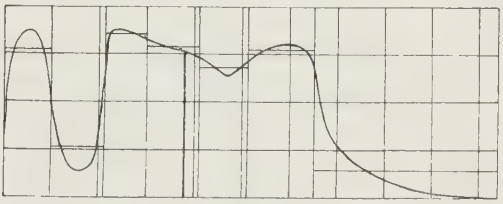

FIG. 12.—MEAN GRAIN SIZE 3.8.

evaporates at a much slower rate and therefore the working range is lengthened very considerably.

Dextrin-Oil Binders

It was not found possible to use linseed oil with bentonite as is suggested owing to the fact that a large proportion of the oil is absorbed by the colloid. Consequently, the amount of oil required to produce a strong core is greatly in excess of that necessary without bentonite, and this leads to the production of large amounts of gas during casting. Moreover, the rate of penetration of oxygen into the bentonite-oil complex is much slower than into the oil alone, which circumstance unduly protracts the baking time.

These objections do not apply to the dextrin-oil binders to nearly the same extent. With these the amount of bentonite required is much smaller because of the green bond conferred by the dextrin and the presence of a fairly large volume of water renders the absorptive property of the bentonite of less consequence. In effect, linseed oil partially destroys the green strength of the bentonite, whilst the dextrin-oil intensifies it.

It was found that with 1 per cent. bentonite and 2 per cent. dextrin oil, the green and dry strengths of the sand were adequate for all ordinary purposes. The permeability could be brought to any desired value by adjusting the respective proportions of the two sands employed.

In use, the sand easily attains the condition of complete compression. Consequently it is impossible for the operator to decrease the permeability by ramming hard, for sand rammed in at one end of a corebox merely results in plastic flow and the emergence of sand elsewhere.

Core Surfaces

Reference has been made to a method whereby the most desirable permeability for a given core may be calculated. This is the permeability which will prevent the core blowing and, at the same time, will not permit the metal to enter the interstices between the grains of sand. The latter point, of course, can be accomplished by other means such as washing with graphite. In the case of large, heavy castings, cores protected in this manner are necessary for other reasons, but in the case of small cores, to which this method is intended particularly to apply, protection is uneconomic and difficult. Moreover, with large cores, and the necessarily large prints, little difficulty is, or should be, experienced from blowing. Consequently, fine-grain sand may be used and the surface tension of the metal will then be sufficient to prevent its penetrating the core.

When molten metal comes into contact with a core, gas is evolved as a result of the decomposition of the bond. This gas, together with the air already present, is expanded to two or three times its normal volume by the rise in temperature. There is therefore, a rapid increase in pressure inside the core. The height to which this pressure will rise depends on the rate at which the gas is liberated and the rate at which it can be evacuated. The former is governed by several factors which cannot be calculated, but it can be found experimentally as is shown later. The latter depends solely on the permeability and the pressure of the gas, but if this pressure becomes equal to or greater than the

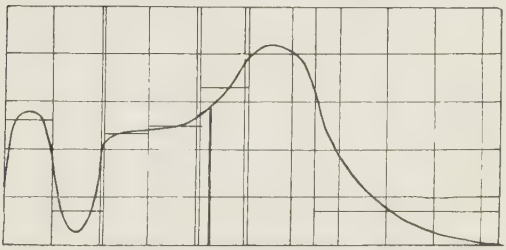

FIG. 13.—MEAN GRAIN SIZE 4.3.

pressure of the metal around the core, then metal will be displaced by gas and a "blow" will appear.

Determination of Metal Pressure

The determining factor then is the pressure of the metal and this may be taken as the product of the height of metal in the runner and the density. The critical period occurs from the point at which the core is submerged to that at which the first skin of solid metal forms around it. Previous to this, exhaustion of the gas can take place, not only through the ports, but also through the face of the mould. For this reason it is found that blowing usually takes place during the period mentioned. Throughout it the pressure is static.

The formula for permeability states that—

$$\text{Permeability} = \frac{\text{Volume of gas} \times \text{length of core}}{\text{Pressure} \times \text{Area of core} \times \text{Time}}$$

or

$$\text{Pe} = \frac{\text{VL}}{\text{PAT}}.$$

Modifying this slightly:—

$$\text{P} = \frac{\text{L}}{\text{PeA}} \frac{\text{V}}{\text{T}}.$$

If, then, the ratio $\frac{\text{V}}{\text{T}}$ could be found, it would be possible to ascertain the value of the pressure in the core by measuring its length, area and permeability. This holds good only for the simple regular form embodied in the formula. Few cores, however, are simple and regular, and it is necessary, therefore, to modify the formula for variations from the simple form.

Assuming that the volume of gas evolved is proportionate to the volume of the core itself, it is necessary to divide the volume of the core by the volume of the simple form. The formula is then multiplied by this ratio. It should be noted that the volume of the simple form is the product of its area and length. The formula then becomes:—

$$\text{P} = \frac{\text{V}}{\text{T}} \frac{\text{L}}{\text{PeA}} \frac{\text{Vol. of core V(c)}}{\text{AL}}$$

or

$$\text{P} = \frac{\text{V}}{\text{T}} \frac{\text{V(c)}}{\text{PeA}^2}.$$

It will be observed that the value L is thus eliminated.

The volume of the core can be found in several ways; for instance, by weighing it and dividing by the density; or it may be calculated from drawings of projected castings.

The ratio $\frac{\text{V}}{\text{T}}$ is the rate at which gas is evolved during the critical period. It is found by experiment, or possibly by experience. It is not possible to calculate it or to estimate it analytic-

ally, because it depends to a large extent on unknown quantities, such as the rate at which heat penetrates the core, the exact composition and temperature of the gas, etc. It bears only a general relationship to the total volume of gas present.

Blowing Control

If, however, a certain core is known to blow, or to give a large proportion of blown castings, it is clear that the pressure in such a core must rise to approximately that of the head of metal. Using this as the value of P in the formula, and taking the dimensions of the core for the other quantities, it is possible to calculate $\frac{V}{T}$ for this particular case.

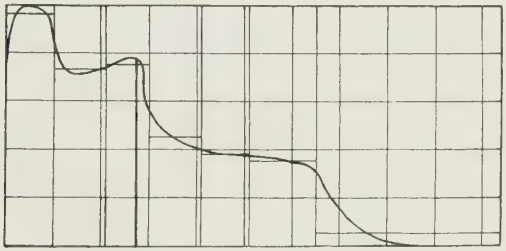

Fig. 14.—Mean Grain Size 2.73.

Alternatively, cores may be made which are intended to blow. For instance, a series of cores of different lengths, but having the same cross-section and permeability, may be cast in a mould adapted to take them. It should be arranged that the cores are cast simultaneously, and the mould should conform to the standard practice. Then, provided that the specimens were made long enough, the longer ones will be found to blow and the ratio $\frac{V}{T}$ calculated for the shortest of these. It is necessary to emphasise that such specimens should be of precisely similar character one to another and to the cores which they are

intended to represent. Differences in permeability, quantity of binder, baking time or temperature will give inconsistent results and, incidentally, such inconsistencies are an indication of variable practice.

The value of the ratio $\frac{V}{T}$, so obtained, is used to calculate the pressure P developed by any other core made from the same materials and used under the same conditions. If it is found that this approaches the pressure of the head of metal, then it is probable that blowing will occur, and the core should be modified accordingly. Similarly, if it is found that the gas pressure is low, compared with head of metal, then penetration is likely, and roughness will result.

There are several ways in which suitable modifications may be effected. The best is to adjust the permeability by admixing more or less fine or coarse sand accordingly as it is required to raise or lower the permeability. Alternatively and where possible the length or cross-sectional area of the core may be altered. For instance, the pressure developed is proportional to the cross-sectional area; that is to the square of the diameter and consequently a small increase in diameter may result in a considerable decrease in the pressure. Patternmakers are usually generous in machining allowances at points where cores issue from castings and it is often possible to reduce this, thereby increasing the diameter of the core.

Alternative Methods

Another way is to raise or lower the gasifiable matter in the core by adjusting the quantity of binder used or altering the baking time or temperature. This is not advisable because it implies departure from a presumably satisfactory standard process and the cores will be deficient in some respect. It is, however, useful as a last resort, for example, in the case where the limit of permeability has been reached with the sands usually employed. In one such case it was found beneficial to bake the cores for a longer time and

at a higher temperature than usual, thereby eliminating a persistent case of blowing.

It should be pointed out that to increase the head of metal only is not a remedial measure. This has the effect of admitting metal to the mould at a faster rate and consequently the rate at which the gas is evolved increases. In effect, the ratio $\frac{V}{T}$ is increased roughly in proportion to the increased head. To maintain the same rate of flow into the mould with increased casting pressure, the size of gates and runners must be reduced, and this entails other difficulties which it were better not to encounter. The modification required should take the form of alteration to the core itself along the lines suggested

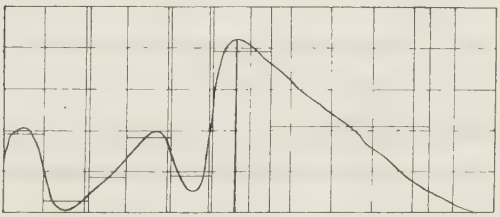

Fig. 15.—Mean Grain Size 5.66.

and not to extraneous conditions. By so doing the stability of other factors is not affected.

The permeability required for the calculation is that of the core itself and not that of an arbitrary standard. This, however, should offer little difficulty, since it is only necessary to measure the permeability of specimens made according to the adopted practice.

The area is taken as being that of the outlet or port. This is not strictly correct, but the inaccuracy is comparatively small. Where there are more than one outlet for the gases, the term A^2 becomes $A_1^2 + A_2^2 +$ etc., where A_1 relates to the size of one outlet, A_2 to that of another, etc.

For ordinary bondless oil-sands containing 2 per cent. linseed oil and baked for 1 hr. at

380 deg. Fah. (193 deg. C.), the ratio $\frac{V}{T}$ appears to be about 700 c.c. per min. For the green-bond sand previously described baked for the same time and at the same temperature it is about 750 c.c. per min. No definite figure can be given for black sand, but it appears to be considerably lower. These figures, however, are intended only as a rough guide since the ratio must vary according to individual practice. Conditions should be arranged so that the pressure developed is about half to three-quarters of the casting pressure and, if this be done, the method is eminently suitable for use under practical conditions.

In conclusion, the writer desires to express his regret that it has not been possible to adduce proof of all the statements made. To do so would unduly prolong the Paper and serve little useful purpose, since he believes that such statements will be generally acceptable and are, in fact, self-evident.

He also wishes to express his appreciation to Messrs. Peglers, Limited, of Doncaster, for their kind permission to publish data collected in their foundry and his sincere thanks to Mr. Austin Crowther for his helpful criticisms.

DISCUSSION

Mr. A. Tipper (West Bromwich), in thanking the author for his paper, said he had approached the sand problem from rather a different angle from the usual, but had given opportunities for criticising certain points. For instance, with regard to the interpretation of the curves relating to grain size, it was stated that one could obtain an idea from those curves of the rate of change of grain size; but Mr. Tipper suggested that the shapes of the curves would depend more or less on the apertures of the sieves and might not show the actual variation in size of grains. The shapes of the curves the author had produced were not very different from the shapes obtained by plotting the actual weights of sand between sieve sizes.

There was still much to be said in favour of using cores made with a naturally-bonded sand. The author had advocated using a silica sand with Bentonite in order to obtain certain properties; but naturally-bonded sands, used in moderation, would give very similar properties, and although the permeability was decreased by using a naturally-bonded sand, the difference

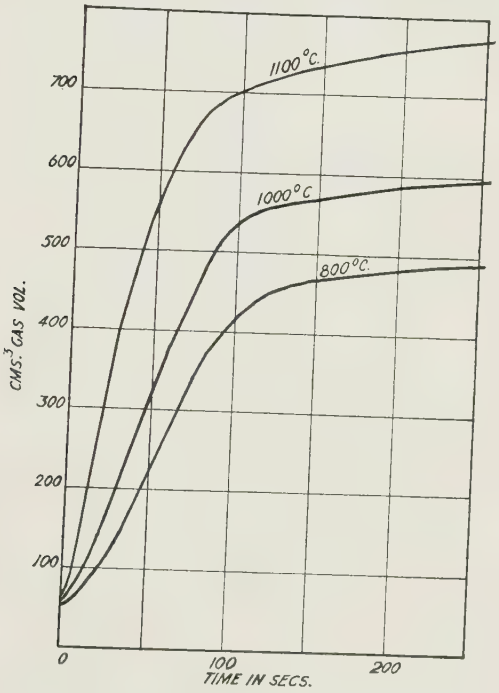

Fig. 16

was not very marked if one used a suitable natural sand. For example, in some tests he had carried out the difference in permeability was only from A.F.A. 120 to A.F.A. 95, whilst the percentage of moisture required in the naturally-bonded sand mixture was actually higher than that required in the Bentonite-silica sand mixture.

With regard to "blowing control," or the measure of the rate of gas evolution from the cores, the author's formula was based on conditions applying to the permeability test, and he had applied that formula, which held good only under certain fixed conditions, to more or less practical conditions in a mould. Mr. Tipper doubted that that could result in producing correct figures. The speaker had measured the actual rate of gas evolution under fixed conditions, and from those figures one could calculate the permeability necessary to allow the gas generated to escape. Those figures could be based on definite laboratory experiments, and gave results which were more easily obtainable and suitable for a method of control than were those obtained by measuring the ratio $\frac{V}{T}$. Rather than calculate a value based on some very variable factors, it was better in his opinion to obtain a figure based only on laboratory conditions for the purpose of control. He would be glad to show to the author some curves indicating rate of gas evolution—and which, by the way, gave values not very different from the values stated in the paper. The author had given a figure of 750 c.c. per minute as representing the rate of gas evolution from an oil sand made with 2 per cent. linseed oil; and in actual measurements it was found that the rate of gas evolution from a core made with a washed silica sand and 2 per cent. linseed oil was 600 c.c. per minute, at a temperature of 1,100 deg. C. as is shown in Fig. 16.

Mr. Ben Hird, after expressing his congratulations to the author, stressed the remark made in the paper, "that by studying sand control he had overcome some of his difficulties;" it should be emphasised, he said, that if sand, and sand control were studied from every point of view, many of the difficulties now being encountered would be overcome, or, at any rate, considerably reduced.

Speaking on behalf of the Institute's Sub-Committee on Sands and Refractories, of which he is a member, Mr. Hird asked if the author

would describe the apparatus he had used for obtaining his permeability figures from the dry sand cores.

The President, who commented that Mr. Howitt had been to considerable trouble and had exercised great care in the preparation of the paper, said it was a paper of great importance and one which merited a good discussion. He urged, therefore, that members should make it a point of honour to make written contributions to the discussion.

AUTHOR'S REPLY

Mr. Howitt, replying to the discussion, said he had not studied very deeply the rate of change of grain size. The point raised by Mr. Tipper, that the aperture of the sieve affected the actual figure, was of some importance. He pointed out that in the ordinary graph, on which points were plotted, the mere point afforded no criterion of the way in which grains were distributed. The grains were actually present along a range and not at any given point, and therefore, one required a line in order to picture them.

Bentonite was used in cores, of course, to take the place of the bond in natural sand, and the fact that one was able to add more or less bond brought the matter quite under control, as was very desirable, in any foundry. When using a natural sand, one could not add more or less bond, without corresponding change in permeability.

It seemed that Mr. Tipper was under some slight misapprehension with regard to gas evolution. In the first place, laboratory experiments could not show the rate at which gas was evolved from a core, because one did not know the actual composition of the gases or their temperature, so that one had only the permeability figure to give an idea of the rate at which the gases were evolved. Very little was known, of course, concerning the rate of penetration into a sand core; it involved the questions of pouring temperature, the rate of admission of the metal to the mould and the rate at which the heat was transferred to the mould and to the core, so that the rate

of penetration was incalculable. In his opinion the best way was to find out by experiment. Most foundries worked under some standard condition, of course, as when making a particular class of work, and under that condition one could get a very fair idea of the rate at which gas was evolved from a certain type of core. Again, many foundries had not a laboratory and had not facilities for ascertaining the rate of gas evolution. However, he would be glad to discuss the matter further with Mr. Tipper, and was pleased that it had aroused interest. Finally, he promised that he would describe in writing the apparatus which he had designed and made for his work.

Written Reply to Mr. Hird

In response to Mr. Hird's request for a description of the method used to measure the permeability of the actual cores, this is done in the following manner:—

A plaster impression of the pattern, complete with prints, is first made in two parts. This, of course, is precisely similar to the mould except that it is impermeable. The corresponding core is then placed in one half, the other half placed over it and clamped. Mercury is introduced into the space between the core and the plaster through a suitable orifice in the top. It is necessary to seal the joints between the core and plaster which is accomplished by a rubber ring around the core print or by plasticine or other plastic material. The joint between the two halves of the mould is sealed with thick oil or grease. Reference to the accompanying diagram will make this quite clear (Fig. 17).

This device is then connected to an aspirator arranged to deliver air at constant pressure and a suitable volume passed through the system. The time taken and the fall in pressure across the specimen are measured, which together with the dimensions of the specimen are all the data required to calculate its permeability.

If required the experiment may be made between certain parts of the core by stopping up

such of the inlets as are not required. Alternatively, in order to study the permeability of certain individual parts, the core may be broken and suitable portions introduced into rubber bungs which are connected to the constant pressure apparatus. This method has the disadvantage that the experiment cannot be pursued to its logical conclusion by making castings with the tested cores, although it may yield valuable information.

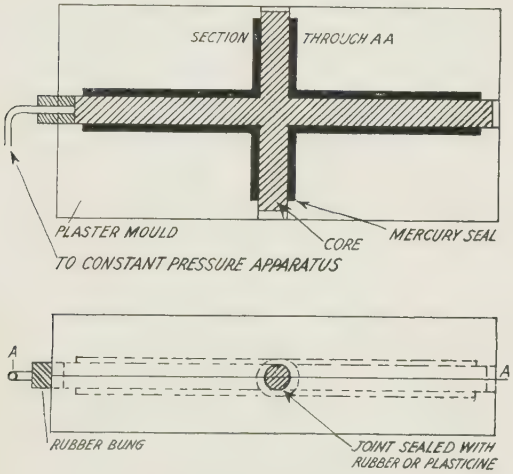

Fig. 17.

The ramming of green sand specimens is done on a machine which consists essentially of a counterpoised beam (B), Fig. 18, which is allowed to rest on a roller secured to the ramming head (R). In vertical alignment with R is another ram (R_1), the connecting rod of which extends downwards and is threaded to pass through the handwheel (H). Weights of any desired size are hung from (B) so that the force applied to the ram may be of any required magnitude.

In use, a quantity of sand is placed in a tube (T) which is introduced between the two rams and into which they fit. Load is applied by

turning the handwheel so that the ram (R_1) moves upwards thereby compressing the sand against the ram (R). When the sand is compressed as far as possible under the particular force applied, the whole system of tube, sand and rams commences to move upward, which movement is indicated by a pointer attached to the beam (B). The load is then removed, the tube disconnected and the specimen extracted from it. The tube may be hinged to facilitate the extraction.

This particular machine was adopted in order to make possible the study of the properties of sand under various conditions of ramming. It is none the less suitable for routine testing, since

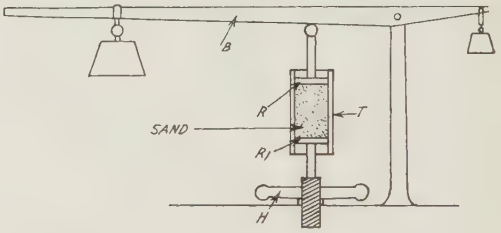

Fig. 18.

the sequence of operations occupies only a few seconds and the force applied may be adjusted to correspond with that used on the moulding machines.

Mr. Hird's Written Contribution

Mr. Hird wrote that he thanked Mr. Howitt for his description of the apparatus he used for testing dry sand; also his ramming machine for green-sand specimens. The methods were ingenious, but had little or no comparison with standard practice of sand testing; therefore, it was almost impossible to correlate results with other data. Considerable expense and time must be entailed in making and using the plaster-of-paris formers if a number of cores of different types required investigation. The permeability of sand could be obtained from a simple straightforward

standard test-piece of standard density. Variations of density due to different methods of ramming in the foundry would remain a subject for close supervision, whether the test-piece was in the form of the actual core or the standard test-piece. Therefore, except for experiments and investigations, he thought the standard apparatus was preferable and far more reliable.

Author's Written Reply

Mr. Hird's somewhat sweeping criticism was, he felt, hardly justifiable. It should be pointed out that the apparatus was originally designed solely for research purposes, and not as Mr. Hird appears to think, for routine work. Mr. Hird states that the methods had little or no comparison with the standard practice of sand testing, and up to a point he is correct. It was deemed advisable to obtain some information on the behaviour of sand under the conditions obtaining in actual practice, which information could not be obtained by arbitrary methods. It was not suggested that the methods were in any way supercessionary, but they could give much information which was unobtainable otherwise, and provided the means to maintain the close supervision which Mr. Hird points out was necessary. The permeability of a standard specimen was not necessarily that of a core or mould made from the same sand, and it was necessary to know in what degree they differed and to work with actual data. Otherwise the properties would not respond to systematic treatment.

STEEL CASTINGS WITH SPECIAL REFERENCE TO ALLOY STEELS

By W. H. Hatfield, F.R.S., D.Met. (Member)

Introduction

The principal steel foundry of Messrs. Thos. Firth & John Brown, Limited, is situated at Scunthorpe, in Lincolnshire, and is, therefore, unfortunately too far from Sheffield for a visit from the Institute on this occasion. This is regretted, as it would have given the directors much pleasure to have had the opportunity of inviting the members to see the lay-out and steel-foundry methods in use. With the formation of Thos. Firth & John Brown Company, the Sheffield foundry of Messrs. Thos. Firth & Sons, Limited, was merged with that of Messrs. John Brown & Company at Scunthorpe, and much capital was expended in creating a joint foundry of first-class efficiency. Members are, however, visiting other steel foundries well representative of the best modern steel-foundry practice.

A few months ago, the author had the pleasure of presenting the exchange Paper with the United States upon this subject, and therefore found himself in some little difficulty as to exactly what aspects of the matter should be now dealt with. After consideration it was decided that, in view of the aspects dealt with by other writers of Papers for this Conference, the author might most usefully deal with the range of steels which are now available in cast form.

To-day excellent steel castings are produced in practically all the steels which have been developed; the ordinary high-tensile alloy steels, wear-resisting steels, steels of special magnetic properties, corrosion- and acid-resisting steels, heat-resisting steels and many others. Indeed, the author welcomes this opportunity of indicating the extent of the success of the modern steel

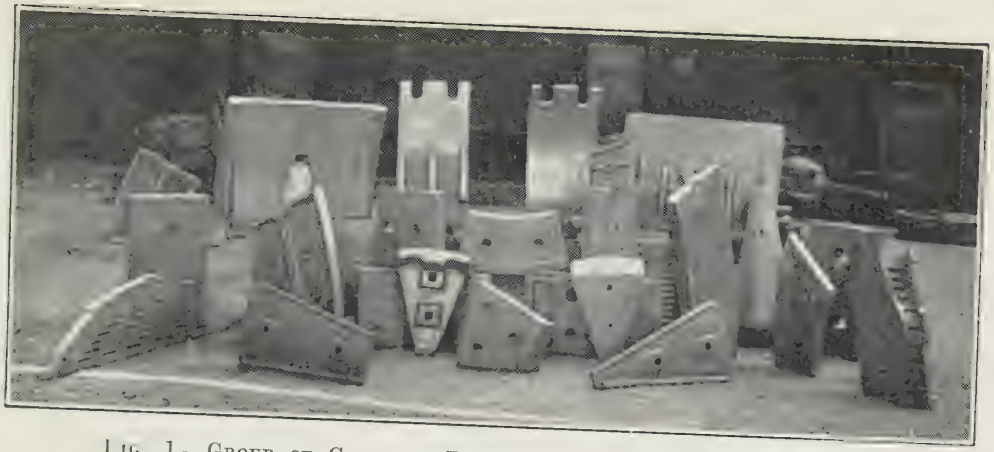

FIG. 1.—GROUP OF GRINDING PLATES MADE IN CARBON CHROMIUM AND AUSTENITIC-MANGANESE WEAR-RESISTING STEELS

foundries in producing castings covering such a wide range of physical and other properties.

Alloy Steel Castings

Carbon-steel castings containing up to 0.40 per cent. of that element have a tensile strength from 28 to 40 tons per sq. in., coupled with reasonable ductility; but with the increase in carbon content the ductility becomes progressively less. It has, however, been found that by having resort to the addition of special elements to the composition of the steel, greater ductility can be obtained with greater tensile strength, and not only so, but by greater percentages of the added elements, entirely new characteristics are conferred.

In Table I some of the most important types of steel are listed together with the mechanical properties which the steels possess in the condition in which they are usually put into service.

It will be noticed that in the steel containing $1\frac{1}{2}$ per cent. manganese, the same tensile strength as a 0.40 per cent. carbon steel is obtained by raising the manganese content to $1\frac{1}{2}$ per cent. and lowering the carbon to 0.25 per cent. This drop in the carbon content, however, gives a marked increase in toughness. A similar steel containing $1\frac{1}{2}$ per cent. manganese and 0.45 per cent. carbon is considerably harder, whilst still remaining reasonably tough.

What is already well known concerning the annealing of carbon steels applies with equal or greater force to alloy steels, and it must be understood that heat-treatment is the necessary complement of the alloy addition. Given correct heat-treatment, however, the table shows that greatly improved mechanical results are obtained.

The $1\frac{1}{2}$ per cent. manganese steels find useful application in various types of relatively heavily-loaded transmission gears and pinions, as well as for such details as excavator digger teeth which demand toughness as well as hardness.

The addition of nickel and chromium to steels, whilst raising the cost, nevertheless produces

Class.	Analysis.	H
Carbon Steel	0.20 per cent. C	Anneal
,, ,, ...	0.30 per cent. C	Anneal
,, ,, ...	0.40 per cent. C	Anneal
,, ,, ...	0.60 per cent. C	Anneal
,, ,, ...	0.75 per cent. C	Anneal
Alloy Steel	1½ per cent. Mn { *a.* 0.25 per cent. C	Anneal
	{ *b.* 0.45 per cent. C	Anneal
		O.H. 8
		T. 600/
,, ,, ...	Ni-Cr	Anneal
		O.H. 8
		T. 550/
,, ,, ...	Ni-Cr-Mo	Anneal
		A.H. 8
		T. 550/
,, ,, ...	C-Cr	Anneal
		O.H. 8
		T. 550/
Rustless Steel	14 per cent. Cr Stainless	O.H. 9
		T. 700/
,, ,, ...	18 per cent. Cr, 2 per cent. Ni to B.S.I. Specification S.80	O.H. 9
		T. 500/
Acid-Resisting Steel ..	18 per cent. Cr, 8 per cent. Ni. "Staybrite" type	A.C. or
,, ,, ..	Special 18 per cent. Cr, 8 per cent. Ni, "Staybrite" Welding Quality	A.C. or
Heat-Resisting Steel ..	26 per cent. Cr, 10 per cent. Ni ..	A.C. 10
,, ,, ..	20/25 per cent. Cr, 8/12 per cent. Ni, 3/4 per cent. W	A.C. 10
,, ,, ..	30 per cent. Cr	O.H. 10
,, ,, ..	Ni-Cr-Fe Alloy (60 : 20 : 20) ..	A.C. 10
High Permeability Steel ..	Low C	Anneal
High Temperature Steel ..	Mo { *a.* 0.20 per cent. C ..	Anneal
		A.H. 87
	{ *b.* 0.30 per cent. C ..	Anneal
		A.H. 87
Shock Resisting Steel ..	Mn-Mo	Anneal
		A.H. 87
Wear-Resisting Steel ..	C-Cr	Anneal
		O.H. or
		T. 550/
,, ,, ..	Austenitic Mn	W.Q. 1

Class.	Essential Analysis.	C.	Si.	M
Carbon Steel ..	0.20 per cent. C	0.21	0.27	0.
,, ,, ..	0.30 per cent. C	0.32	0.24	0.
,, ,, ..	0.40 per cent. C	0.39	0.26	0.
,, ,, ..	0.60 per cent. C	0.62	0.22	0.
,, ,, ..	0.75 per cent. C	0.73	0.27	0.
Alloy Steel ..	1½ per cent. Mn { *a*. 0.25 per cent. C	0.23	0.31	1.
	{ *b*. 0.45 per cent. C	0.43	0.24	1.
,, ,, ..	Ni-Cr	0.36	0.28	0.
,, ,, ..	Ni-Cr-Mo	0.32	0.23	0.
,, ,, ..	C-Cr	0.43	0.29	0
Rustless Steel ..	14 per cent. Cr Stainless..	0.29	0.48	0
,, ,, ..	18 per cent. Cr, 2 per cent. Ni, Stainless	0.17	0.31	0
Acid-Resisting Steel	18 per cent. Cr, 8 per cent. Ni	0.10	0.73	0
Heat-Resisting Steel	26 per cent. Cr, 10 per cent. Ni	0.14	1.6	0
Heat-Resisting Steel	20/25 per cent. Cr, 8/12 per cent. Ni, 3/4 per cent. W	0.14	1.76	0
,, ,,	30 per cent. Cr	0.29	0.97	0
,, ,,	Ni-Cr-Fe Alloy (60:20:20)	0.97	0.84	1
High Permeability Steel	Low C	0.09	0.32	0.
High Temperature Steel	Mo { *a*. 0.20 per cent. C	0.18	0.24	0.
	{ *b*. 0.30 per cent. C	0.32	0.36	0.
Shock-Resisting Steel	Mn-Mo	0.25	0.26	1.
Wear-Resisting Steel	C-Cr	0.73	0.34	0.
,, ,,	Austenitic Mn	1.07	0.72	12.

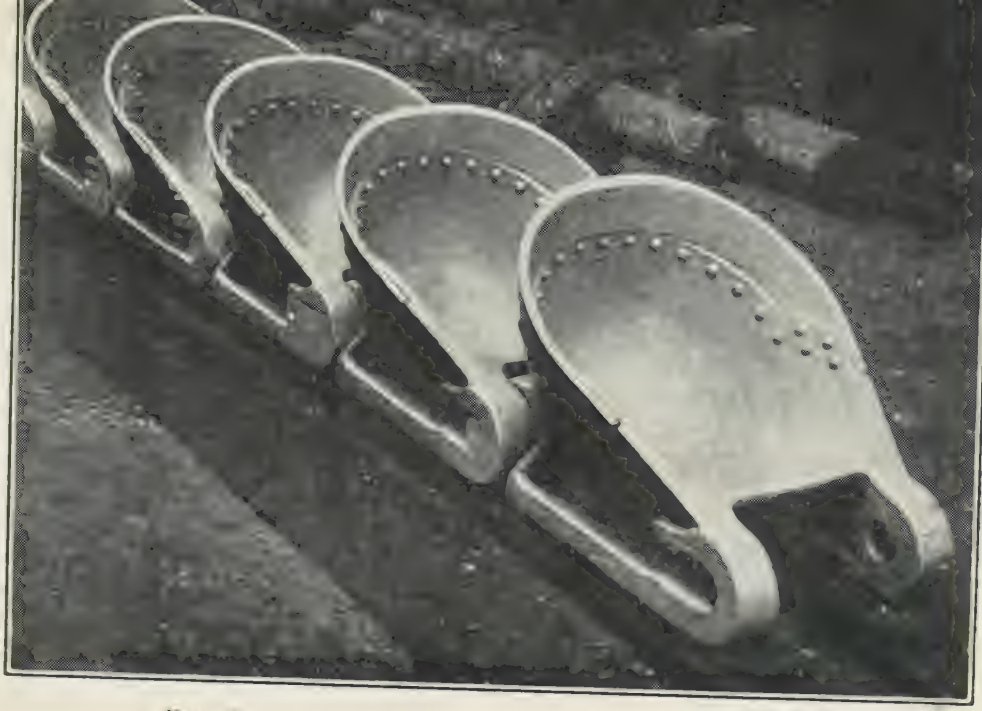

FIG. 2.—DREDGER BUCKETS IN AUSTENITIC MANGANESE STEEL.

steels having a high yield point and great toughness; whilst the further addition of molybdenum again increases the possible strength of the material inducible by heat-treatment, and yields a steel suitable for the most severe conditions of stress combined with shock, as are met particularly in such applications as, for instance, tractor and excavator machinery. Indeed, nickel-chromium and nickel-chromium-molybdenum steel castings are the ones which will stand up satisfactorily to the heavy duty experienced in caterpiller-tractor mechanisms.

Finally, the carbon-chromium steel listed in Table I is one which possesses, in addition to strength and toughness, the intrinsic hardness to withstand considerable wear, and is used, for instance, for cast-steel gear blanks.

Rust- and Acid-Resisting Steel Castings

It was not many years ago that steel castings subjected to corrosive conditions had either to be frequently replaced or the plant had to be designed to their exclusion. To-day, there are steels suitable for foundry work which resist the most corrosive conditions. In Table I the main types are illustrated. The ordinary 14 per cent. chromium steel is essentially a rust-resisting steel; that is to say, it is employed for such castings as those used in dock-gate assemblies, steam plant, and other similar conditions in which mildly-corrosive conditions are experienced.

The 18 per cent. chromium, 8 per cent. nickel steels, on the other hand, are acid-resisting, and are employed in many applications in the chemical industry and also in all types of decorative work, such as window fasteners, door handles, hooks, taps and other bathroom fittings, as well as for such industrial work as pump castings, cast dye vats of special design, water wheels, etc. The founding of these steels presents a number of fascinating and interesting problems. At one end of the scale is the problem of setting a core in position so that a bathroom tap may be cast having a uniform wall thickness of about $\frac{3}{32}$ in.

At the other end is the problem of setting up the mould and cores for a turbine wheel weighing several tons, having a heavy hub and a heavy rim 7 or 8 ft. in dia., between which lie perhaps a dozen and a-half curved blades of light section, tapering to less than an inch in thickness at the trailing edge; upon the exact position and accuracy of these blades the efficiency of the whole machine depends. The problems would not be easily solved in a non-ferrous foundry, and they are much more difficult with a steel cast at a temperature between 1,600 and 1,700 deg. C. having a contraction on cooling of $\frac{9}{32}$ to $\frac{5}{16}$ in. per ft. Actually, both extremes and many intermediate types of such castings are produced.

Heat-Resisting Steel Castings

The development of heat-resisting steels and their application to foundry production is another relatively recent development of the technology of alloy steels. In Table I the properties of the principal groups of heat-resisting steels suitable for castings have been correlated. The first two groups of analyses are austenitic steels; they cannot be hardened by heat-treatment, and are put into service in the softened condition, which, it will be noted, is one of comparatively high tensile strength and extreme ductility and toughness.

A steel containing 26 per cent. chromium and 10 per cent. nickel is a critical composition possessing good fluidity, and is eminently suitable for castings. In certain cases, however, it is desirable to have a higher nickel content in the region of 20 to 25 per cent. to assist the resistance of the steel to oxidation at temperatures in the region of 1,050 deg. C. Whilst there is little to choose as regards mechanical strength at ordinary temperatures between the different austenitic steels, addition of the element tungsten appreciably raises the strength at high temperatures, especially in the region of 700 to 900 deg. C.

Steels containing 30 per cent. chromium possess excellent resistance to scaling, but are

Class.	Analysis.	Heat-treatment.
Carbon Steel ..	0.20 per cent. C	Annealed 900 deg. C.
,, ,, ..	0.30 per cent. C	Annealed 890 deg. C.
,, ,, ..	0.40 per cent. C	Annealed 860 deg. C.
,, ,, ..	0.60 per cent. C	Annealed 840 deg. C.
,, ,, ..	0.75 per cent. C	Annealed 810 deg. C.
Alloy Steel ..	1½ per cent. Mn { 0.25 per cent. C	Annealed 920 deg. C.
	{ 0.45 per cent. C	Annealed 900 deg. C. or O.H. 870 deg., T. 600/650 deg. C
,, ,, ..	Ni-Cr	Annealed 900 deg. C. O.H. 870 deg., T. 550/650 deg. C
,, ,, ..	Ni-Cr-Mo	Annealed 900 deg., A.H. 870 deg. T. 550/650 deg. C.
,, ,, ..	C-Cr	Annealed 900 deg., O.H. 870 deg. T. 550/650 deg. C.
Rustless Steel ..	14 per cent. Cr Stainless	O.H.960/980 deg., T.700/750 deg.
,, ,,	18 per cent. Cr, 2 per cent. Ni Stainless (S.80 type)	O.H.960/980 deg., T.500/550 deg.
Acid-Resisting Steel	18 per cent. Cr, 8 per cent. Ni, Stainless ("Stay-brite" type)	A.C. or W.Q. 1,050/1,150 deg. C.
Heat-Resisting Steel	26 per cent. Cr, 10 per cent. Ni	A.C. 1,050 deg. C.
Heat-Resisting Steel	20/25 per cent. Cr, 8/12 per cent. Ni, 3/4 per cent. W	A.C. 1,050 deg. C.
Heat-Resisting Steel	30 per cent. Cr	O.H. 1,050 deg., T. 600/700 deg. C
,, ,,	Ni-Cr-Fe Alloys	A.C. 1,000 deg. C.
High Permeability Steel	Low C	Annealed 900 deg. C.
High Temperature Steel	Mo { 0.20 per cent. C ..	Annealed 900 deg., A.H. 870 deg. T. 650 deg. C.
	{ 0.30 per cent. C ..	Annealed 900 deg., A.H. 870 deg. T. 650 deg. C.
Shock-Resisting Steel	Mn-Mo	Annealed 900 deg., A.H. 870 deg. T. 650 deg. C.
Wear-Resisting Steel	C-Cr	Annealed 920 deg., O.H. or A.H. 870/900 deg., T. 550/650 deg. C
,, ,,	Austenitic, 13 per cent. Mn	W.Q. 1,000 deg. C.

Contraction allowance.	Freezing range, liquidus/solidus.	Distinctive properties.
in. per ft.	1,525/1,490 deg. C.	Dead mild steel; tough and ductile.
in. per ft.	1,520/1,460 deg. C.	Higher tensile strength.
in. per ft.	1,510/1,430 deg. C.	Greater hardness and resistance to surface wear.
in. per ft.	1,500/1,390 deg. C.	Considerable surface hardness, but not much
in. per ft.	1,490/1,360 deg. C.	toughness.
in./$\frac{7}{32}$ in. per ft.	1,510/1,450 deg. C.	Increased tensile strength, hardness and
in./$\frac{7}{32}$ in. per ft.	1,500/1,400 deg. C.	toughness.
in. per ft.	1,510/1,450 deg. C.	Medium high tensile strength and great toughness.
in. per ft.	1,500/1,420 deg. C.	High tensile strength and maximum toughness.
in. per ft.	1,510/1,450 deg. C.	Medium high tensile strength and good resistance to surface wear.
n. per ft.	1,500/1,430 deg. C.	Resistance to rust and mild corrosion.
n. per ft.	1,500/1,420 deg. C.	High tensile strength and improved corrosion-resistance.
in./$\frac{5}{16}$ in. per ft.	1,470/1,400 deg. C.	Resistance to acid attack and other severe forms of corrosion (non-magnetic and high coefficient of expansion.)
in./$\frac{5}{16}$ in. per ft.	1,450/1,390 deg. C.	Excellent resistance to scaling and fair strength at high temperatures in the region of 1,000/1,050 deg. C. (non-magnetic and high coefficient of expansion).
in./$\frac{5}{16}$ in. per ft.	1,450/1,390 deg. C.	Excellent resistance to scaling and great strength at elevated temperatures in the region of 1,000/1,050 deg. C. (non-magnetic and high coefficient of expansion).
ı. per ft.	1,450/1,380 deg. C.	Excellent resistance to scaling but brittle in the cold.
ı. per ft.	1,300/1,250 deg. C.	Excellent resistance to scaling and great strength at high temperatures.
n. per ft.	1,530/1,490 deg. C.	High magnetic permeability.
n. per ft.	1,520/1,470 deg. C.	Increased strength at elevated temperatures in the region of 400/500 deg. C.
n. per ft.	1,520/1,440 deg. C.	
. per ft.	1,500/1,430 deg. C.	Excellent toughness and resistance to shock.
n. per ft.	1,490/1,340 deg. C.	Considerable intrinsic hardness and resistance to wear by attrition.
n. per ft.	1,400/1,350 deg. C.	Great toughness and resistance to wear by crushing, hammering and pounding (non-magnetic and high coefficient of expansion).

usually brittle in the cold; whilst nickel-chromium alloys of the type 60 per cent. nickel, 20 per cent. chromium, 20 per cent. iron, though perhaps not, strictly speaking, steels at all, pos-

TABLE IV.—*Physical Properties*

Class.	Type of steel.	Coefficient of expansion, 20/700 deg. C.
Carbon Steel	0.20 per cent. C	0.0000148
,, ,,	0.30 per cent. C	0.0000148
,, ,,	0.40 per cent. C	0.0000148
,, ,,	0.60 per cent. C	0.0000147
,, ,,	0.75 per cent. C	0.0000146
Alloy Steel	1½ per cent. Mn + 0.25 per cent. C	0.0000148
	1½ per cent. Mn + 0.45 per cent. C	0.0000148
,, ,,	Ni-Cr	0.0000148
,, ,,	Ni-Cr-Mo	0.0000148
,, ,,	C-Cr	0.0000148
Rustless Steel	14 per cent. Cr Stainless	0.0000124
,, ,,	18 per cent. Cr, 2 per cent. Ni Stainless (S.80 type)	0.0000120
Acid-Resisting Steel	18 per cent. Cr, 8 per cent. Ni Stainless ("Staybrite" type)	0.0000185
Heat-Resisting Steel	26 per cent. Cr, 10 per cent. Ni	0.0000171
,, ,,	20/25 per cent. Cr, 8/12 per cent. Ni, 3/4 per cent. W	0.0000171
,, ,,	30 per cent. Cr	0.0000120
,, ,,	Ni-Cr-Fe Alloys	0.0000119
High Permeability Steel	Low C	—
High Temperature Steel	Mo + 0.20 per cent. C	0.0000148
	Mo + 0.30 per cent. C	0.0000148
Shock-Resisting Steel	Mn-Mo	0.0000148
Wear-Resisting Steel	C-Cr, Wear-Resisting	0.0000148
Wear-Resisting Steel	Austenitic, 13 per cent. Mn	0.0000198

sess a maximum combination of strength and resistance to scaling at elevated temperatures.

Other Special Alloy Steel Castings

Finally, there is a miscellaneous collection of special foundry steels developed to fulfil specialised conditions of service. The first steel

of the last group but one in Table I is a carbon steel of high magnetic permeability used for castings in electrical-generating machinery and cast-steel crane magnets. This high permeability

Various Types of Foundry Steels.

oefficient of expansion, /400 deg. C.	Thermal conductivity. C.G.S. Units.	Magnetic properties.	Air-Hardening Characteristics.	Tenacity at very high temperatures soon after solidification.
0.0000134	0.130/0.110	Magnetic	None	Normal.
0.0000133	0.120/0.105	Magnetic	None	Normal.
0.0000133	0.120/0.095	Magnetic	None	Normal.
0.0000133	0.110/0.075	Magnetic	None	Normal.
0.0000132	0.100/0.070	Magnetic	None	Normal.
0.0000133	0.090/0.085	Magnetic	Very slight	Normal.
0.0000132	0.090/0.085	Magnetic	Very slight	Normal.
0.0000133	0.105/0.080	Magnetic	Present	Normal.
0.0000133	0.100/0.080	Magnetic	Marked	Slightly increased.
0.0000133	0.110/0.080	Magnetic	Present	Normal.
0.0000115	0.045/0.040	Magnetic	Marked	Normal.
0.0000113	0.040/0.035	Magnetic	Marked	Normal.
0.0000175	0.035/0.030	Non-magnetic	None	Somewhat increased.
0.0000159	0.030/0.025	Non-magnetic	None	Somewhat increased.
0.0000159	0.030/0.025	Non-magnetic	None	Greatly increased.
0.0000111	0.035/0.030	Magnetic	Marked	Normal.
0.0000133	0.025/0.020	Non-magnetic	None	Greatly increased.
—	—	Magnetic	None	Normal.
0.0000134	0.130/0.110	Magnetic	None	Slightly increased.
0.0000133	0.120/0.100	Magnetic	Very slight	Slightly increased.
0.0000133	0.090/0.080	Magnetic	Very slight	Slightly increased.
0.0000133	0.110/0.080	Magnetic	Marked	Normal.
0.0000192	0.030/0.025	Non-magnetic	None	Normal.

is obtained by keeping the elements carbon, silicon and manganese down to the lowest possible limits, but in so doing the greatest care must be exercised to make sure that the casting remains sound.

The addition of molybdenum to ordinary carbon steel increases its strength at tempera-

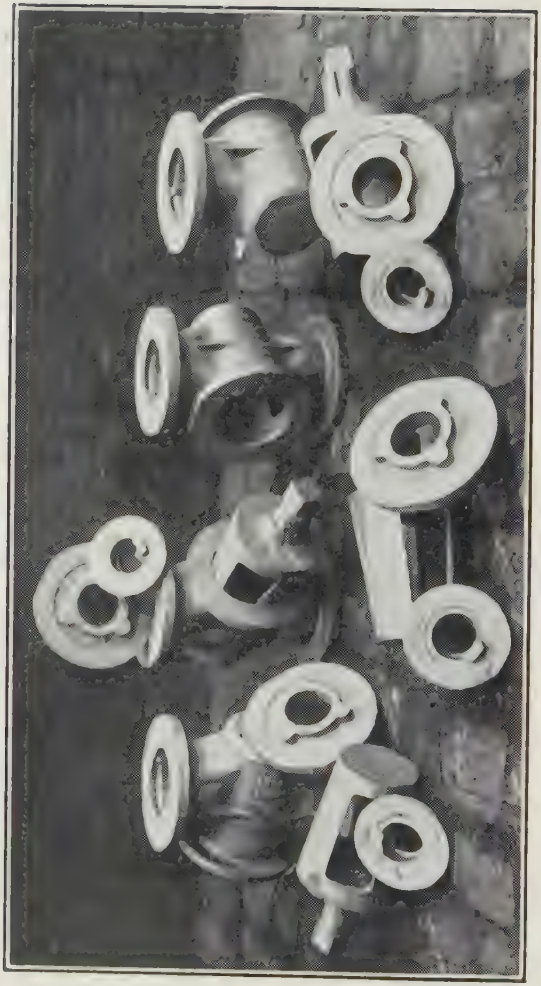

FIG. 3.—GROUP OF STAINLESS STEEL VALVES.

tures above the normal. Comparing the 0.20 per cent. carbon steel containing molybdenum with straight 0.20 per cent. carbon steel, it will be seen that at ordinary temperatures it is only 25 per cent. stronger. Between 400 and 500 deg. C., however, its limiting creep stress is about double. Since the creep-stress is a true gauge to the behaviour of a material at high temperatures, the addition of molybdenum renders the steel just twice as strong under such conditions. Such a steel is invaluable for castings employed in high pressure steam plant of one type and another, such, for instance, as turbine casings and steam chests.

Simultaneous addition of $\frac{1}{4}$ to $\frac{1}{2}$ per cent. molybdenum and $1\frac{1}{2}$ per cent. manganese gives a steel which is characterised by extreme toughness and resistance to shock, although this property is not revealed in the test data shown in the table. Actually, it is best seen in service when castings of this analysis stand up even to the shocks and stresses met with in pile-driving equipment.

This brief survey may be completed by instancing two entirely different types of wear-resisting steel for the foundry. The carbon-chromium type, containing 0.50 to 0.75 per cent. carbon and about 1 per cent. chromium (molybdenum may also be added in the highest grades), attains considerable intrinsic hardness by heat-treatment. In fact, the higher grades reach 400 Brinell. The 13 per cent. manganese steel is, however, austenitic in character, which means that after heat-treatment it is relatively soft. On the other hand, when it is put into service under heavy crushing pressures, such as are withstood by a crusher jaw working on hard material, it " work-hardens " to a considerable extent. In other words, the more work there is put upon it, the greater is the hardness which it develops to resist the deformation.

In the most general terms, therefore, the carbon-chromium type of steel is used for castings employed in crushing and grinding plant,

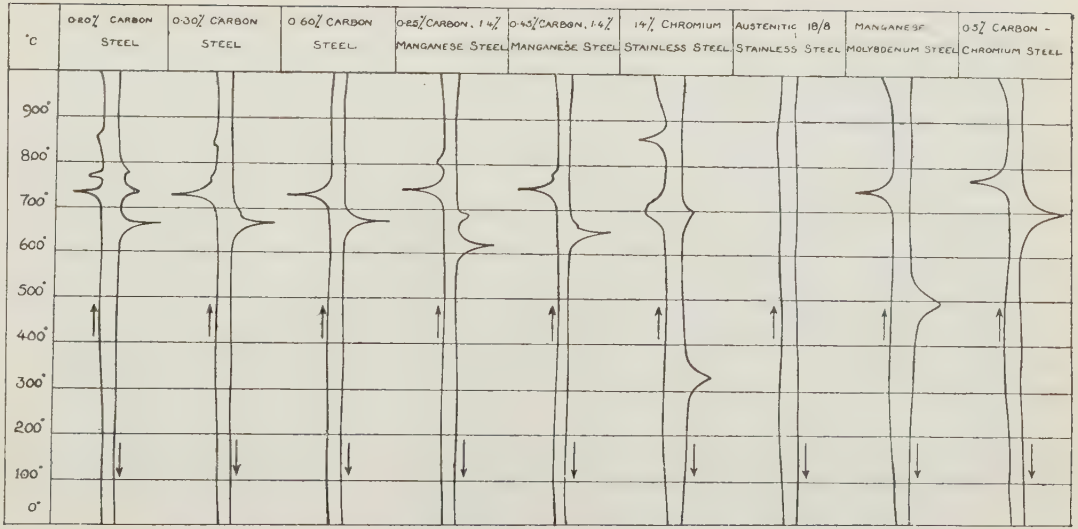

FIG. 4.—HEATING AND COOLING CURVES OF VARIOUS FOUNDRY STEELS.

excavating and digging machinery, cement and brick-manufacturing equipment for these items subjected to wear without any heavy crushing or grinding pressures. But when the conditions of service provide adequate work-hardening, the 13 per cent. manganese austenitic steel is to be preferred.

Such, in brief outline, is the development up to the present day of the application of alloy steels to the steel foundry. Their introduction has brought in their train a number of problems

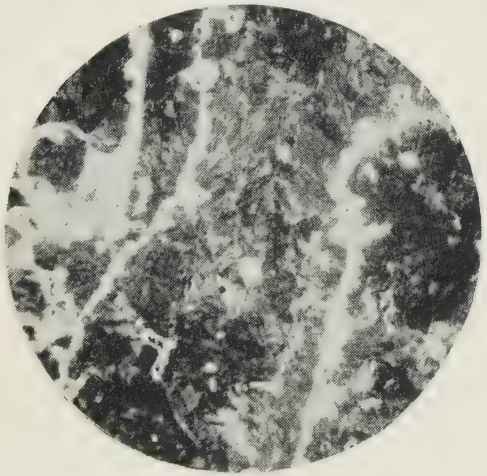

FIG. 5.—0.40 PER CENT. CARBON STEEL. AS CAST. × 200.

concerning fluidity of the steel, heterogeneity, contraction and porosity, refractoriness and mechanical strength of the sand; but such problems are yielding effectively before the patient work of our foundry technologists. Foundry technique has adapted itself to the use of this wide variety of alloy steels; and to-day carbon and alloy-steel castings, whilst not displacing other forms of steel, nevertheless occupy an essential position in every branch of engineering.

In Table II is given a summary of the typical applications of these various steels, together with an analysis typical of each case for the purpose of correlation with other data which is subsequently given.

Essential Data Concerning Foundry Steels

In Table III data are given concerning these typical steels. Columns 1 and 2 contain a description of the steel, and in Column 3 the corresponding heat-treatment to put the steel

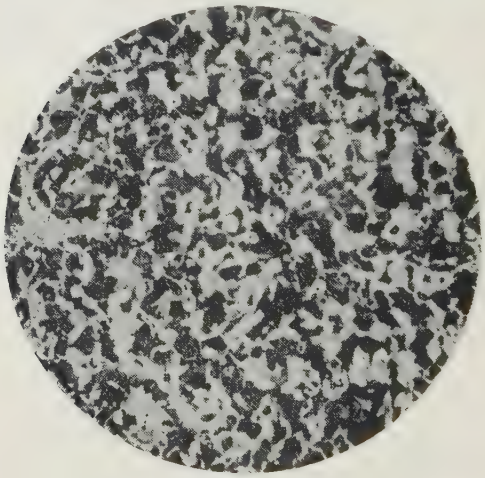

Fig. 6.—0.40 per cent. Carbon Steel. Annealed at 900 deg. C. × 200.

into the optimum service condition is given. The fourth column gives the allowance which should be made for the contraction of the steel on solidification, and it should be noted that this varies with the change in analysis; whilst in the fifth column the author has made an attempt to correlate the information extant concerning the freezing ranges of the various steels. The higher figure represents the liquidus, or the temperature at which solidification commences;

whilst the lower limit, on the whole of less practical importance, is the solidus. The solidus should not, however, be lightly overlooked, because it is of value in determining at what temperature a large casting should be stripped. Finally, in the last column the essential properties of each type of steel are listed.

Peculiarities of the Different Foundry Steels

The data collated in Table IV are of practical importance to the foundryman, but there are in

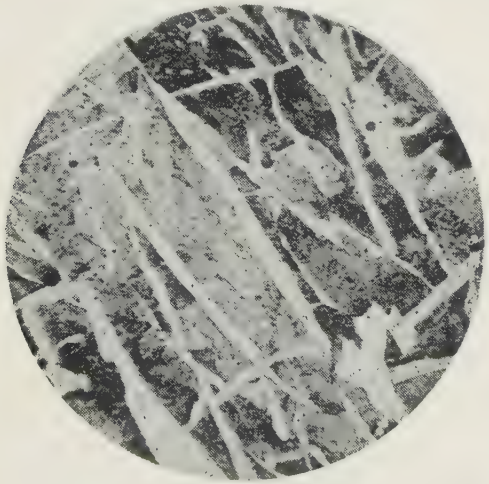

FIG. 7.—0.45 PER CENT. CARBON, 1.4 PER CENT. MANGANESE STEEL. AS CAST. × 200.

addition one or two other essential properties of steels which lend themselves less readily to quantitative measurement. The most important of these is probably "fluidity." When handling this wide range of alloy steels in the foundry, due account must be taken of the peculiarities of each steel, and each composition commands its own technique.

Dead soft magnet steel lacks fluidity, although medium-carbon steels possess good fluidity and high-carbon steels are characterised by extreme

fluidity, but have a greater tendency towards "blowing" than lower-carbon steels. The greatest care must, therefore, be taken in drying and venting the moulds. The 1½ per cent. manganese steels possess only fair fluidity, and, owing to a slightly increased coefficient of contraction in the solidification range, they are more liable to hot pulling. Whilst ordinary carbon-chromium steels possess reasonable fluidity, nickel-chromium steel tends to be sticky,

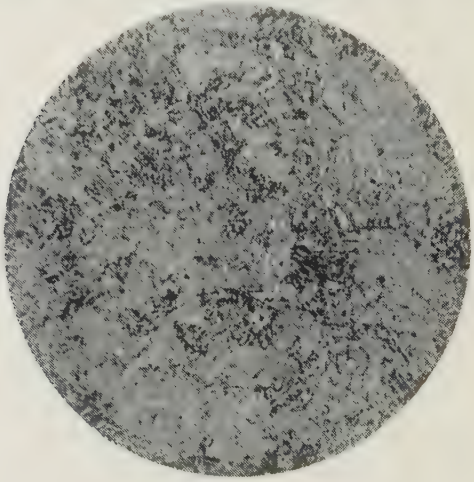

FIG. 8.—0.45 PER CENT. CARBON, 1.40 PER CENT. MANGANESE STEEL. ANNEALED, 900 DEG. C.; OIL-HARDENED, 870 DEG. C., AND TEMPERED, 650 DEG. C. × 200.

and the addition of molybdenum accentuates this tendency. The molybdenum steels, especially the higher-carbon alloy, possess reasonably good fluidity, but allowance should be made in moulding for the increased contraction. The manganese-molybdenum steel castings should, for the same reason, be moulded with care; and it is a feature of great interest in connection with this steel, that it appears to have an unusually high liquid contraction; there is an unusually

large shrinkage of the metal between the casting temperature and the beginning of solidification, and for this reason large heads must be allowed for.

The high-carbon, 1 per cent. chromium, wear-resisting steels have quite good fluidity, and are reasonably free from hot pulling; but the 14 per cent. and 30 per cent. chromium corrosion- and heat-resisting steels are more sticky.

Finally, the 13 per cent. manganese wear-resisting steel and the various high chromium-

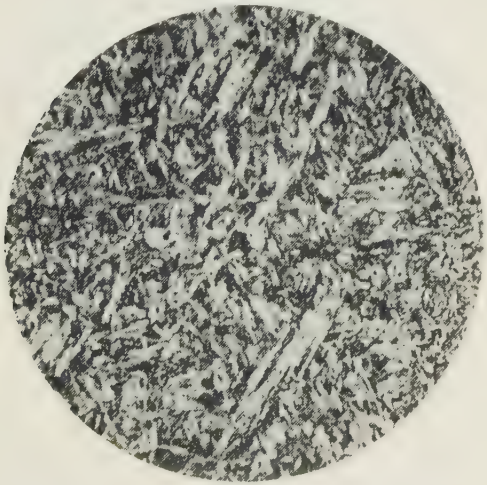

FIG. 9.—MANGANESE-MOLYBDENUM STEEL. AS CAST. × 200.

high nickel corrosion- and heat-resisting steels are all austenitic in character. They all have a high coefficient of contraction on solidification, which means that care and knowledgeable understanding is required to prevent hot-pulling. These austenitic steels have a high coefficient of expansion and contraction when solid, which in turn means that a further contraction of considerable magnitude takes place on cooling from the solidus to room temperature.

It is, therefore, general practice to strip these castings when still red hot, and so relieve the metal of the constriction imposed upon it by the sand.

Sands and Moulds Used for the Different Types of Special Steel Castings

For the lightest sections, green-sand or skin-dried moulds are usually employed; and great

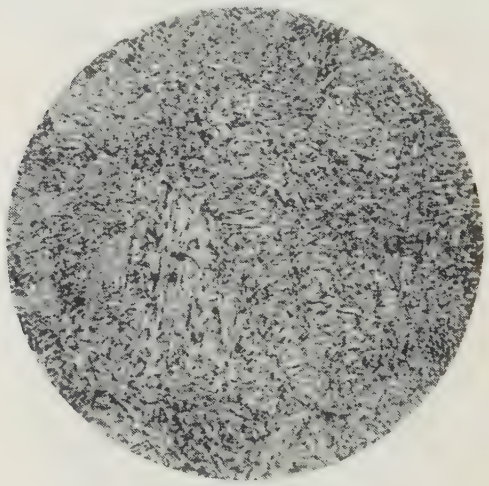

FIG. 10.—MANGANESE-MOLYBDENUM STEEL. ANNEALED 900 DEG. C., FURNACE COOLED TO 650 DEG. C., REHEATED TO 870 DEG. C., AND AIR-COOLED. × 200.

care should be taken in the preparation of the sand to give high permeability, and permit the free escape of gases from the mould. For high-class castings of light section oil sand is, however, on the whole to be preferred. These general principles are to some extent over-ruled by consideration of the quality of steel being cast.

High-carbon steels, for instance, are liable to "blowing," and for this reason they should

never be cast in green-sand moulds; and care should be taken to see that the moulds are properly dried. The same remarks apply, of course, to the high carbon-chromium wear-resisting steels and, in some measure, to the other alloy steels, with the notable exception of the austenitic manganese and 18/8 "Staybrite" types of steel. A very high finish is obtained on castings of light section in these latter qualities, using green-sand or skin-dried moulds.

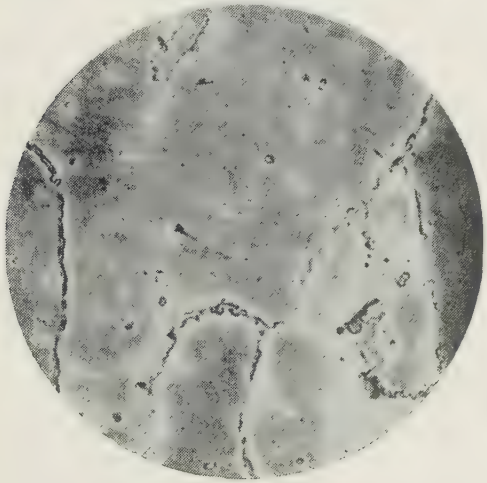

FIG. 11.—12 PER CENT. MANGANESE STEEL. AS CAST. × 200.

For castings of heavier section dry-sand moulds are generally used for both carbon and alloy-steel castings; whilst for the heaviest work a very strong clay-bonded sand or compo. is usually employed in this country. A large grain size is necessary to give mechanical strength, and high refractoriness is, of course, essential, since the greater mass of metal involved means that the mould remains at higher temperatures for a longer time. Complex sections, such, for example, as frames, bolsters and drag boxes,

owing to their intricacy of section, require a special moulding technique combining oil-sand cores for machine faces, green-sand cores to permit of easy contraction and green or skin-dried moulds.

This leads the author to consider another aspect of the choice of sand. Internal cores and mould construction must always be planned to allow for the contraction of the steel on cooling from the beginning of solidification to the tem-

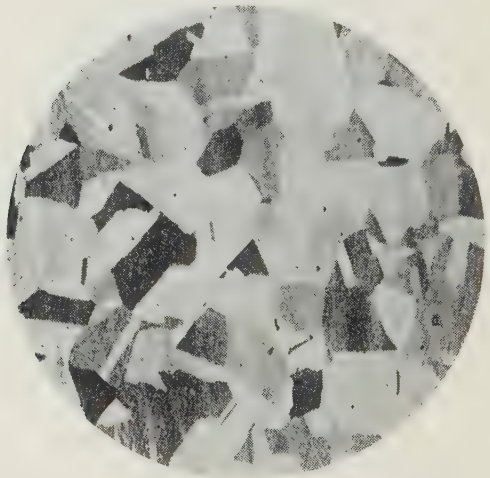

FIG. 12.—12 PER CENT. MANGANESE STEEL. ANNEALED AND WATER-QUENCHED FROM 1,000 DEG. C. × 200.

perature of stripping. This contraction varies slightly from one alloy steel to another, and is of greatest importance in the austenitic chromium-nickel corrosion and heat-resisting steels and the 13 per cent. manganese wear-resisting alloy. These steels, besides having a high contraction on solidification, contract substantially on cooling. All cores must, therefore, be made from a sand which is sufficiently weak to yield

to the contracting steel, and similarly care must be taken that "pulls" are not produced at the junction of flanges and webs with the body of the casting.

Carbon-chromium steels, 1½ per cent. manganese steels, nickel-chromium, and high-chromium stainless and heat-resisting steels, need the necessary care to counter the possible effects of their tendency towards air-hardening, accentuated by varying thickness of section. For this

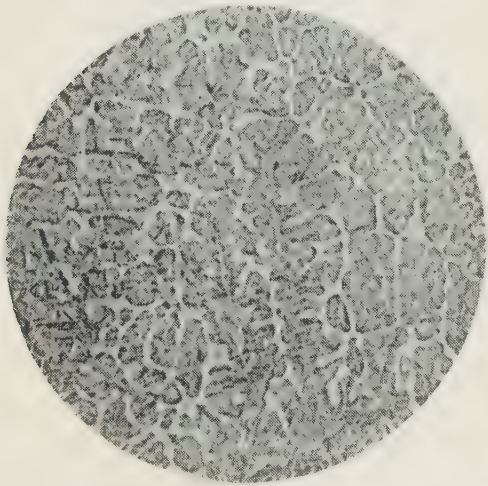

Fig. 13.—14 per cent. Chromium Stainless Steel. As cast. × 100.

reason it is sound practice to strip and charge them into the annealing furnace whilst still hot.

It is also essential to strip the austenitic steel castings at the earliest possible moment and so relieve the stresses set up in the casting due to its somewhat high contraction. Heads and risers should be cut off whilst it is still red hot, and all cores removed, so that, when the casting is quenched, the effect of quenching may penetrate right through to the innermost parts.

Perfect Castings

Metallurgical science necessarily plays a leading part in the modern steel foundry. The first requirement in the production of a perfect casting is a supply of clean and fully-deoxidised steel. Although it is theoretically impossible to reduce the oxygen content of steel to zero unless the whole procedure is carried out *in vacuo*, the great strides made in the technology of steel-

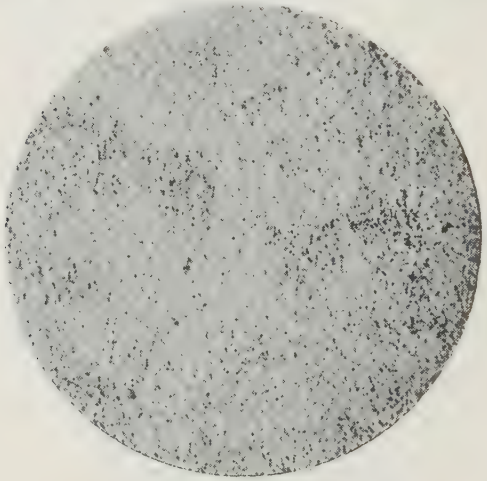

FIG. 14.—14 PER CENT. CHROMIUM STAINLESS STEEL, OIL-HARDENED AT 970 DEG. C. AND TEMPERED AT 700 DEG. C. × 200.

making during the last decade or two renders it possible to approach closely to this condition.

Then the mould itself must have been properly prepared, and there are one or two considerations not already mentioned worthy of a moment's attention. The box must be of sufficient size to give an adequate thickness of sand between it and the casting; and strengthening bars must not be too near to the incoming hot metal. In addition to the mould itself, the cores should be efficiently "vented," a point

which is sometimes overlooked; and if there are several internal cores together, the vents must be linked up. Precision in moulding, the checking of sizes and the position of cores are essential to the production of perfect castings.

Much controversy rages over the relative merits of stopper and lip pouring. In favour of the former is conservation of heat in the ladle, absolute steadiness of the stream (if the nozzle be properly set) and cleaner steel; whilst lip pouring has the advantages of greater flexi-

FIG. 15.—18 PER CENT. CHROMIUM, 8 PER CENT. NICKEL STEEL. AS CAST. × 50.

bility and control over the rate of flow of the metal and avoidance of high ferrostatic pressures.

Each method has its applications, but if the metal is poured in a steady stream into the mould at the correct rate and temperature, without surging inside the mould or splashing outside it, it is immaterial which method is employed.

The casting temperature is critical for three reasons. It must be high enough to give sufficient fluidity to the steel to enable the casting

to be run. It must be low enough to prevent fusion of the sand to the casting. It must be low enough to give fine crystal structure and minimum heterogeneity.

The first point is self-explanatory, and in connection with the second an interesting example might be quoted. A certain standard magnet casting weighed 7 cwts. and had a thickness of about 2 in. When it was run in less than 70 sec., the sand was burnt on and the skin was

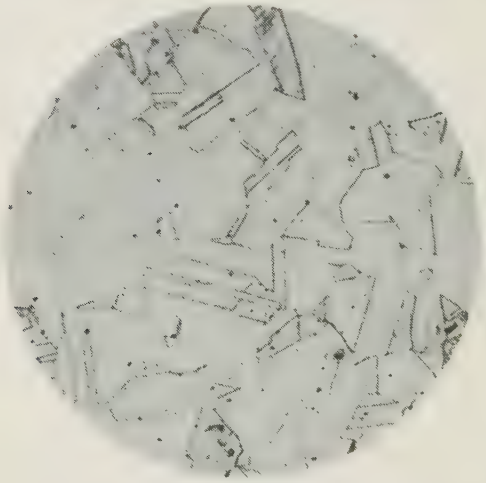

FIG. 16.—18 PER CENT. CHROMIUM, 8 PER CENT. NICKEL STEEL. AIR-COOLED FROM 1,150 DEG. C. × 200.

bad; but when the pouring time was more than 70 sec., the casting had a perfect blue skin. All factors other than temperature were under complete control, and the temperature is inversely proportional to the pouring time.

Much work has been carried out in recent years on the heterogeneity of steel ingots, and one point which is very clearly indicated is that the lower the casting temperature, the less is the segregation. The other important effect of

temperature on structure is that the lower the casting temperature, the smaller is the grain size.

It might perhaps be thought that, because every casting is heat-treated, the primary structure is of no importance; but this is a fallacy. The primary structure is more or less outlined by a fine network of non-metallic matter, according to the quality of the liquid steel, and, although the primary grain structure is replaced by a much finer structure during normalising, this network cannot be entirely removed by heat-treatment. In a casting, therefore, the fine-grained structure produced by heat-treatment is superposed upon and within the coarser network associated with the primary structure; and in the perfect casting the pouring temperature should, therefore, be as low as is compatible with a fluid and easily-run steel. It is for this reason that the author has laid stress upon the freezing point of different steels and has correlated the information in Table III, because it is only by studying their freezing ranges, in conjunction with fluidity, design of mould and weight of steel to be cast, that the optimum casting temperature can be arrived at.

Macro- and Micro-Structure

The primary structure formed by the steel on solidification is not only coarse, but is the cause of the low ductility and in certain cases brittleness associated with the "as-cast" condition. A prolonged heating at a temperature well above the upper critical point of the steel gives opportunity for the diffusion of elements which either as elements or compounds enter into solid solution in the steel, and subsequent cooling through the critical range results in recrystallisation and the formation of a refined structure.

The temperatures of the critical points are affected by the composition of the steel, and in Fig. 4 a number of curves, illustrating the comparative thermal phenomena, are presented. Heat-treatment must always be based on the carefully-determined thermal data on each steel.

The coarse nature of the primary crystallisation as well as the fine structure produced by heat-treatment, is illustrated in Figs. 5 to 16, which give a comparative study of different foundry steels in the condition "as cast," and after the heat-treatment normally applied to put them into the optimum service condition.

Were any further evidence needed to show the fundamental importance of even simple heat-treatment, the figures in Table V are convincing.

TABLE V.—*Effect of Heat Treatment on Plain Carbon Steels.*

	0.20 per cent. Carbon steel		0.40 per cent. Carbon steel	
	As cast	An-nealed	As cast	An-nealed
M.S. tons per sq. in.	34	32	42	40
Y.P. tons per sq. in.	22	16	22	21
Elong. per cent.	17	30	4	18
R. of A. per cent.	15	50	4	24

Conclusion

Within the limitations as regards the space at his disposal, the author has attempted to give some idea of the various special steels applied to foundry practice; has attempted to present and correlate essential data needful for a proper working-out of foundry technique; and, so far as space allowed, has dealt with the applications and the properties which determine these applications.

The subject is an extensive one, and in many directions much intensive further investigation is necessary to explore fully the various possibilities of service in the steels now available in cast form. Much additional research is necessary to confirm and to extend the type of data with which the author has endeavoured to deal. So much is this appreciated by the leading firms that advantage is being taken of the possibilities of collective research with the object of extending fundamental knowledge for the industry.

The Joint Committee of the Iron and Steel Institute and the Federation of British Iron and Steel Manufacturers fully merits the support of each constituent firm in the industry in its determined attempt in this field. The need for filling in the gaps in our knowledge as regards the characteristics of the different steels in the liquid state as affected by varying temperature, and the changes in properties which occur at and following upon solidification, is very real. The author trusts that this Paper may assist in some measure in focussing certain aspects of the matter.

DISCUSSION

Dr. P. Longmuir, M.B.E. (Past-President), congratulated Dr. Hatfield on his excellent survey of alloy-steel castings, and said that the figures given with regard to the physical properties of these castings were, as Dr. Hatfield had said, conservative. The four tables in the Paper covered the field admirably, and the physical values given towards the end were of very real utility. Emphasising his point that the maximum values given in respect of the physical properties in Table I were conservative, Dr. Longmuir said independent tests on the 18/8 chromium-nickel steel as produced under Dr. Hatfield's supervision, the tests extending over many months, showed that those values were very regularly exceeded. It was not often that, when examining alloy castings of this character, one obtained such conformity as between the makers' results and the results of independent checks. Dr. Longmuir also congratulated Dr. Hatfield on his presentation of the treatments given, which constituted perhaps the most valuable feature of the Paper. Although treatments were more widely applied to castings than was generally recognised, very few of the firms who treated the castings had published their results. Indeed, to some extent in steel-foundry circles those treatments were still regarded as deep, dark, and mysterious secrets. The advice given in the Paper with regard to moulding was also

excellent, and perhaps Dr. Hatfield would forgive him if he said that that advice could be carried to other than alloy-steel castings.

Value of Co-operative Research

Dr. T. Swinden also stressed the value of the Papers which Dr. Hatfield had contributed to the mechanical engineers, automobile engineers, aeronautical engineers, and various other bodies, and the generosity of Dr. Hatfield and his company in putting forward such data. One usually expected from Dr. Hatfield Papers such as that which he now presented, and which were simply invaluable. It was difficult to discuss such a Paper, because it was a statement of carefully-considered facts, and it was of great benefit to have in so concise a form reliable information concerning these various types of alloy castings.

Dr. Swinden also reminded the meeting, as had Dr. Hatfield, in the course of the discussion on ingot moulds that morning, that a Joint Committee on Steel Castings was operating; and as a vice-chairman of two such joint committees, Dr. Swinden emphasised that some of the steelmakers possessing considerable resources were placing before the community, at considerable expense, a great deal of valuable information. As Dr. Hatfield had stated in the last paragraph of his Paper, it was important to fill in the gaps in the information available; the filling of those gaps was rightly the business of the whole community, and it was justifiable to urge that all interested parties should co-ordinate their data and place them before the Committee, on which they had ample opportunity for representation, and so help to improve the whole industry of the country.

Influence of Alloyed Steel on Carbon Steel Practice

Mr. C. W. D. Townsend could not refrain from associating the information contained in Dr. Hatfield's paper with the statement made by Sir William Larke in the course of the " Edward

Williams" Lecture, in which he had visualised the results of using steels having a strength three times as great as that of the steels available at the present time. The paper by Dr. Hatfield was helping to achieve that end, by placing on record definite data which could be used by all who were interested. He had set an example, which, if followed by other firms who possessed special information, would rapidly bring them to the stage at which they should be able to produce such steels as Sir William Larke had visualised, the production of which would, of course, increase foundry problems. Dr. Hatfield not only appreciated the scientific and technical difficulties, but also the human ones. Practical foundrymen recognised that they must develop a standard of technique in line with the development of the various steels. The multiplication of the steels produced in the steel foundry had added vastly to foundrymen's problems; it had also had a reflex action on the manufacture of carbon steel castings, inasmuch as it had brought forward rapidly those problems which had to be overcome in connection with alloy steels, thus helping the carbon steel casting manufacturer to reach a position which otherwise he might not have reached for many years to come. The paper constituted a milestone in the development of the technique of the production of alloy steel which could be cast into articles for use in the engineering trades.

Properties of Steels Melted *in Vacuo*

Professor J. H. Andrew (Dean of the Faculty of Metallurgy, University of Sheffield), in thanking Dr. Hatfield for the paper, said that very frequently in his Lectures he used Dr. Hatfield's results and had found them extremely useful. He asked if Dr. Hatfield considered that a cast structure, properly heat treated, would give results equal to those of a forging. Experience in the industry, in conducting tests on material from a 40-ton ingot which had not been subjected to forging, was that by successful heat treatment, results were obtained equal to, and

in some cases better than, those obtained from forged material.

It was pleasing that Dr. Hatfield had emphasised the importance of the initial cast structure, for he (Professor Andrew) imagined that the final properties of a casting depended upon initial structure to a greater extent than was realised by many people.

Reference was also made to the possibilities of vacuum melting, it being suggested that in order to make perfect steel we would have to melt *in vacuo*. Vacuum melting gave a loss of carbon from 15 to 18 per cent., there was loss of practically the whole of the manganese, and one eliminated the oxygen. He had found that if the steel were deprived of all the oxygen, without effecting the other elements, the tensile strength was reduced by from 5 to 15 tons. He was beginning to think that the oxygen was an essential ingredient in steel, in certain amounts.

Finally, Professor Andrew asked whether it was possible to remove the castings from the moulds whilst they were hot and place them in a soaking pit, in order to avoid contraction stresses during cooling.

Sand Data Required

Mr. N. D. Ridsdale asked if Dr. Hatfield could give, in addition to the very useful collection of data contained in the paper, some actual figures on the properties of the moulding sands to which reference had been made. It was stated in the paper that in general the sands should have high permeability, and so forth; now that such properties could be measured readily it seemed a pity not to have also some actual data as to the permeability number, and bond strength, say on the A.F.A. scale, in respect of both the green and the dry sands which Dr. Hatfield had used. Mr. Ridsdale pointed out that if Dr. Hatfield had no facilities, he could obtain data, through the Secretaries of the Branches of the Institute, as the result of the questionnaire issued by the Sub-Committee on Sands and Refractories.

Annealing Temperature and Fluidity

Mr. J. E. Mercer thought practical foundrymen would agree that the tables which Dr. Hatfield has drawn up were a good practical guide to those engaged in the steel and alloy castings trade. Mr. Mercer referred to the high-permeability steel mentioned in one of the tables, which, of course, has a very low carbon content. The annealing temperature was given as 900 deg. C. From personal experience Mr. Mercer did not consider this possible. Could Dr. Hatfield give his opinion on this?

Discussing the fluidity of steel, Mr. Mercer questioned a statement in the Paper concerning low-carbon steel not being as fluid as a steel containing 0.4 to 0.6 per cent. carbon. In his opinion, the fluidity depended firstly on the quality of material charged into the furnace, and secondly upon the length of time the steel remained in the furnace. There was no real reason why the lower-carbon steel should not be as fluid as the one with the higher carbon content.

AUTHOR'S REPLY

Co-operative Research

Dr. Hatfield said that he was gratified by the discussion, and it was also a real pleasure that the discussion had been opened by Dr. Longmuir, one of the Institute's earliest Presidents, whose comments were very much appreciated. He also thanked Dr. Swinden for having emphasised the general idea of collective research. It would be agreed that if ours was a mechanical civilisation, and depended on the application of science to industry, and the development of large manufacturing units, surely those large units, such as Brown-Firth, the United Steel Companies, the English Steel Corporation, the General Electric Company, and so on, having big laboratories financed by public money—and it was public money if one analysed the shareholdings—should be generous, and should put

before the public at large the findings of their research. In a number of outstanding cases that had been done, but, as Dr. Swinden had said, it was not correct and proper that individual companies should be expected to do all the investigatory work for industry. On that assumption the British Iron and Steel Federation, through its Research Council, was endeavouring to provide a mechanism whereby the fundamental research for the whole industry could be done with the aid of collective resources. That was a very necessary phase in the evolution of the steel industry, and he believed it applied more or less to other industries. But he believed the steel industry was setting the pace, and he appealed to all present to do all they could to facilitate and encourage this policy of collectivism and mutual help. The endeavour was to arrive at a condition of things where there was mutual help and collectivism on matters of common interest, whilst at the same time reserving sufficient individuality to the constituent companies, so giving full play to private enterprise. That was a rather British spirit of compromise to fit in with the evolution of modern civilisation. He also expressed appreciation of Mr. Townsend's remarks and agreed with him that the greater study necessary to develop alloy steels must result in the great improvement of mild-steel castings also.

Cast Structures Unequal to Forged

With regard to Prof. Andrew's question as to whether good cast steel could give a performance equally as reliable as forged steel, the answer was, quite dogmatically, "No." The reason was that in making a casting one poured liquid steel into any shape the engineer might have in mind. Even if one subordinated everything else to the production of the most simple form of ingot, it was extremely difficult to be absolutely sure that one produced a perfectly sound, solid and homogeneous piece of steel. In ingot manufacture one was making a standard

design all the time, there being only one object, *i.e.*, to produce a form in which the steel was free from defects, everything else being subordinated to that. But, as the work of the Committee on the Heterogeneity of Steel Ingots had shown, perfection had not yet been attained. How could one expect to meet the difficulties, therefore, if one cast any old shape with liquid steel and allowed it to freeze? For absolute reliability there was everything to be said in favour of forgings as distinct from castings. The point was, however, that the economics of the problem would not in most cases permit of the expense of forging; further, as was evidenced by many Papers presented before various Institutions, the steelfounder was, with time, producing very tolerable castings. He had no wish to depreciate in any sense the reliability of steel castings, but having been asked a definite question, he must answer it in this way, and he considered that answer was final.

Oxygen-Free Steels

With regard to oxygen in steel, he was glad that Prof. Andrew had himself announced the results of the important work he had been doing lately, and which would shortly see daylight as a section of the next Report of the Committee on the Heterogeneity of Steel Ingots. He believed that Prof. Andrew and his collaborators by that work had made a very definite step forward in regard to knowledge; it would appear that the presence of gases was normal in steel, and that if they were taken out one was producing an abnormal material, which Prof. Andrew had found possessed properties entirely dissimilar from those of material from which the gases had not been eliminated. This was a very interesting piece of work.

The removal of castings from the mould while hot and placing them into the furnace was in fact practised; the technology of the special steels must be understood, and all such precautions were taken.

In reply to Mr. Ridsdale, he said he was fully aware of various methods of evaluating sands. Those methods were used, but he had not referred to them in the Paper because they were rather outside its scope, and he had not the time at his disposal to deal with that phase of the matter.

The question raised by Mr. Mercer, as to whether the structure of a high-permeability low-carbon steel casting could be broken down at a temperature of 900 deg. C., depended entirely upon the interpretation of the phrase "broken down." But Dr. Hatfield felt that the answer was "No." A simple treatment at 900 deg. C. did not result in producing a perfectly broken-down structure.

Fluidity

The problem of fluidity was a very wide one. The Steel Castings Committee at the present time was faced with the fact that, important as was the investigation of that problem, it had not yet arrived at a quantitative works method of determining the degree of fluidity—a method which could be used from one works to another, so that the fluidity of a particular steel at a particular temperature in one works could be compared with that of the steel under the same conditions in another works. They all believed that nominally the same steel at a given casting temperature could possess widely-different degrees of fluidity, and it was very possible for a higher-carbon steel having a lower melting point to "appear" to have a less degree of fluidity than a milder steel having a higher freezing temperature. Therefore, he could not answer the question.

RESEARCH ON STEEL CASTINGS

By Professor J. H Andrew, D.Sc. (Member)

It is surprising to find on reviewing the literature how small is the amount of academic research and theoretical consideration given to steel castings, as compared with the work carried out on steel ingots and forged material. A casting is different from a forging with respect to its having undergone no mechanical work, and, as often as not, no heat-treatment. Further, in a casting the mould is usually of sand, excepting in the case of permanent moulds.

Perhaps the greatest trouble experienced with castings is with respect to contraction cavities, and blowholes; the former being largely localised where changes in section occur; whilst the latter source of trouble may arise either through gas in the metal or in the sand. Further, blowholes are necessarily accompanied by segregation, a fact that is not always recognised. With regard to contraction cavities, the writer is convinced that the view of the late Mr. J. H. S. Dickenson, that each and every section of a casting must be regarded as a separate ingot, is correct. This being so, it is essential to provide fluid metal sufficient to supply each particular section as contraction is proceeding.

Research carried out with a view to systematising the method of feeding and arrangement of heads might well be undertaken, for there is no reason whatsoever why, if the conditions advocated could be complied with, and given good metal and moulding, sound casting should not always result. Such a suggestion will naturally call for the comment, that many thousands of different types of castings are made every day in the foundry. This is true, but even so the author is convinced that much could be done by experimental research

founded on logical conceptions to eradicate the troubles that arise through contraction cavities.

A New Alloy Sought

The discovery of an element that when added to steel would reduce the fluid-solid contraction would be invaluable, and this might well be made the subject for investigation. As yet there is very little data on this question, or how such contraction is affected by added elements. Heated moulds supply no solution, for whatever temperature a mould be heated to, the steel will solidify at the same temperature or over the same range of temperature irrespective of the temperature of the mould. The rate of cooling of a liquid or of a solid can be reduced, but the control of the rate of solidification where the range is but narrow is a physical impossibility.

With regard to the formation of blowholes, in so far as gas from the metal is concerned, this could be obviated by the addition of the correct amount of aluminium. Aluminium, however, is known to make the running sluggish, and to give rise to deeper pipe cavities. A high temperature of casting coupled with feeder heads arranged correctly might, however, obviate this defect.

Oxygen-Free Steel

It is, however, an open question as to whether an oxygen-free steel is desirable from the standpoint of its strength. Recent research undertaken in the writer's laboratories has indicated that the tensile strength of steel drops very markedly when all the oxygen is removed. Provided the oxygen remains dissolved in the steel it may possibly be an asset rather than otherwise. Very interesting and profitable investigations might well be conducted on the lines just indicated.

Facing Sand

Blowholes arising from the mould, in the case of green-sand casting, must depend largely upon the porosity of the sand. The usual practice of coating the mould with a fine carbonaceous

facing sand requires looking into. In the first place, carbonaceous gases along with hydrogen are generated at the metal-sand interface. If the sand be insufficiently porous, or the venting insufficiently good, gas will penetrate the metal with the formation of blowholes. The author many years ago was instrumental in introducing into a foundry making large steel castings, a facing sand entirely free from carbon, and the results were so good that the practice was adopted. Research on facing sands, with particular reference to the composition of such sand, would seem to be well worthy of undertaking.

A carbon steel containing less than 0.7 per cent. of carbon begins to solidify with the deposition of almost carbonless iron, the carbon-rich material not solidifying until later. Thus, every steel casting is heterogeneous even at temperatures just below the solidification temperature, and will remain so down to atmospheric temperature. It is, therefore, very necessary to normalise a steel casting, not only to remove casting stresses, but to bring about a greater uniformity of structure.

A correctly heat-treated casting may give tests equal to the same material in a forged condition. Thus, it is possible that castings which can be heat-treated might readily replace the more costly forged material.

Alloy Steel Castings

Alloy steel castings might, under certain conditions, successfully be oil-hardened and tempered, whilst there seems no reason whatsoever why air-hardening steels in which an air-hardening is given subsequent to casting should not come into more general use. An alloy steel having a normal critical point below 400 deg. C. could be safely heat-treated, for the critical change is at a temperature below that at which steels possess good tensile properties, and the tendency to fracture would seem to be very remote.

The particular atmosphere in which a steel is melted is also a matter deserving investigation.

It is quite possible that the atmosphere in which the molten steel is submerged may have an appreciable effect not only on the soundness, but also on the mechanical strength of the resulting castings. It is, for instance, often alleged that the hardness of a quenched steel depends upon the type of furnace in which it is heated for hardening, oil, gas, coal, coke or electric, and there would appear to be some truth in this thought.

The effect of casting temperature upon fluidity is at present receiving considerable attention. There is some reason for the view that the oxygen content of the steel is the controlling influence, so that to make research on fluidity of the greatest value, the oxygen content of the metal should be known, that is to say, should be determined by careful analysis.

In fluidity testing it is essential that all tests should be carried out under exactly the same conditions, and these conditions are by no means easy to comply with. For instance, the metal should be run into the fluidity test mould, at the same rate, from the same initial height, and obviously the same volume of metal must be used. These and other factors are necessary to take account of if absolute results are sought.

Generally speaking, a very considerable amount of valuable research awaits the investigator who has at his service an equipment capable of dealing with small weights of metal, up to half a ton, the necessary means of providing suitable moulds and accurate pyrometers. It is only by carrying out such practical tests in a suitable laboratory, which is in no way concerned with output, or with the soundness of products, but one in which every casting scrapped is in the nature of valuable research, that consistent progress can be hoped for, and much remains to be learned.

Written Communication

Dr. W. H. Hatfield, F.R.S. (Sheffield), wrote that he entirely agreed with Professor Andrew that the greatest trouble in

castings was in respect to blowholes and contraction cavities. As regards the systematising of the method of feeding, whilst he agreed that this was most desirable, the types of casting were so varied that it would be difficult to lay down any simple set of rules and the various foundries each had their own methods of procedure according to their individual experience. Work, however, was being done by the Steel Castings Research Committee on this point.

The writer agreed that an extensive research on the influence of added elements on contraction would be most valuable, but pointed out that this would not eliminate the large solid contraction which, owing to the different rates of cooling throughout the mass, was at least of equal importance.

As regards facing sands, the requirements varied according to the form of castings being made, and from this point of view a foundry working on repetition work, producing large quantities of castings to a particular pattern, had a great advantage. At the same time, a foundry producing castings of miscellaneous types had greater facilities for studying the response of different mixtures to the varying factors.

He was afraid that Professor Andrew was somewhat optimistic in his view that forged material might be generally replaced by heat-treated castings.

With regard to alloy steel castings, the writer did not consider that the fact that the critical point was below 400 degrees C. was any guarantee of safe heat-treatment. Such alloys were most probably air-hardening and high internal stresses had to be met during and after cooling.

As regards details of practice, such as the atmosphere of the melting furnace, casting temperatures, and fluidity, he agreed that these were of great importance but, whilst it should be recognised that it was desirable to have full knowledge of these influences, and to regularise practice where possible, there was a limit to the extent to which this could be applied in foundry work.

A NOTE ON THE INFLUENCE OF TEMPERATURE GRADIENTS IN THE PRODUCTION OF STEEL CASTINGS

By George A. Batty

(*Presented on behalf of the American Foundrymen's Association*)

[American Exchange Paper]

In the production of steel castings in sand moulds, or in moulds formed of other refractory materials, a great deal of attention has been given to the provision of feeding heads of adequate size and proper location to promote soundness—freedom from that mid-section cavity known as enclosed pipe—in all parts of the piece. As the complexity of the design increases, and as sharply differential sections are conjoined or relatively heavy masses imposed on a generally lighter structure in positions which are difficult to reach with feed metal, the difficulty in promoting soundness throughout the complete structure generally increases.

The casting of complex design presents additional difficulties, which increase the liability to failure, the resistance of the mould to the normal contraction of the solidified metal introducing the tendency to hot tearing or cracking. Despite this fact, it is a common foundry experience to find that among the castings most difficult to produce of a grade that is both commercially satisfactory and free from serious metallurgical deficiencies are pieces which are of harmonious or simple design, such as hammer blocks and gear blanks.

In part this is due to the relation of area to mass and in part to the system of gating and heading employed. The relation of surface area to mass of cast metal is briefly but illuminatingly commented upon by Briggs and Gezelius[1] who made a series of four pairs of castings each pair being a sphere and a parallelepiped—and deter-

mined the rate of skin-formation or actual solidification by turning over the mould after a predetermined time interval, and pouring out through the gate the metal which remained liquid.

The sphere and the rectangular block were of identical volume, but the parallelepiped was of 50 per cent. greater surface area than the sphere. The rate of skin formation was found to be almost identical for both sphere and block, but the point of greatest significance to the practical foundryman is that, in the same time intervals, approximately 50 per cent. more metal solidified in the mould producing the parallelepiped than in that producing the sphere.

This set of experiments illustrates quite strikingly what may be defined as " rate of feed demand," which is important to the founder in determining the size and shape of the feeding head to be imposed to promote the internal soundness of the casting. The shape or design of a casting must, therefore, have some considerable bearing upon the ultimate cost by reason of the amount of metal necessary to produce the piece and the concomitant cost of cleaning off the discard.

It is not necessarily to be assumed that the rate of solidification of the parallelepiped will continue to be 50 per cent. greater than that of the sphere, but the reported results of the series of tests show strikingly that the distance of the centre of the mass from the two nearest opposed mould faces has a profound effect upon the rate of solidification—expressed as a progressive proportion of the weight, not as linear thickness of the continuously-thickening solidified envelope—and, therefore, upon the rate of demand for metal from the superimposed feed head.

In the case of the sphere the centre of the mass of the casting proper is equidistant from every part of the mould-metal interface, which, giving the lowest possible ratio of surface-area to mass, predicates the slowest rate of feed demand and, in practice, the greatest amount of

metal to be imposed as a feed head to promote soundness of the cast structure. Briggs and Gezelius did not state the dimensions of the rectangular piece used in their experiments for comparison with the sphere, but what they demonstrated in their comparison may also be applied to a consideration of rectangular shapes of different ratios of surface area to mass. Within fairly well defined limits—prescribed by the "castability" of the metal—it is easier to produce commercially satisfactory castings, in relation to internal soundness, as the ratio of surface-area to mass increases.

The massive casting, say a hammer block, is more difficult to produce free from shrinkage cavity, and is more expensive in the amount of metal required, plus the cost of cleaning or fettling, than is a piece of similar weight, say a simple baseplate, having a much larger ratio of surface area to mass.

The foregoing discussion has had relation to castings produced by what may be considered orthodox steel foundry practice in relation to gating, heading, and pouring procedure—gating into the base of the mould cavity; either filling the mould completely, including the feeding head, through the downgate, or filling the mould proper through the downgate and then filling up the head by pouring directly into it; by using metal as cool as possible, and by filling the mould as quickly as possible. Under such governing conditions it is not possible, even on the simplest forms of castings, to have any pronouncedly favourable temperature gradient in the metal at the moment the mould is filled, and, by reason of the gating employed, the mould will have acquired an adverse temperature gradient related in degree to the pouring rate and to the section thickness of the casting.

Section Thickness and Pouring Rate

Section thickness must be considered in relation to pouring rate (rise of metal in mould per second), and it is common foundry practice to

ensure a high-pouring rate for light sections—a cylinder cast vertically, as instance. Despite this fact, there is likely to be produced in both mould and casting a distinctly adverse temperature gradient which is inimical to the ultimate integral soundness of the cast structure. The observed fact that the metal which appears in the risers and vents of a bottom-poured casting is very much cooler than the metal delivered to the downgate is such a foundry commonplace, so thoroughly in accord with what is to be expected, that its tremendous significance has not been properly appreciated.

The obviously adverse temperature gradient in the metal has been noted and feeding heads provided of such shape and capacity as to show sound metal when they were cut off and the casting dressed down to the proper size. If the feeding heads have to be relatively large in order to promote such apparent soundness and if they are filled through the casting—as distinct from being filled individually from the open top—they may help to promote unsoundness in the lower levels of the casting by causing more metal to be passed through the mould, whereby the adverse temperature gradient is increased in both mould and metal.

A Concrete Example

So far as the feeding heads themselves are concerned, they, being necessarily of considerably heavier section thickness than the part of the casting upon which they are imposed, become reservoirs of heat in proportion as they are reservoirs of metal, and so produce, strictly locally, a favourable temperature gradient. Hence, the apparent soundness of the casting immediately below such feeding heads. To indicate the relevance of temperature gradients a type of casting has been chosen for discussion which had given some considerable trouble by reason of defects which, while being repairable, were of considerable commercial significance. The casting is fairly simple, is of harmonious design and of almost uniform section thickness,

The deficiencies in the casting were all in the lower levels, leaks at the fillets or radiused junction of flange with body, and at bolt-holes on the bottom flange.

The orthodox method of heading and gating which was used for the casting under discussion is illustrated on Fig. 1. The mould was placed

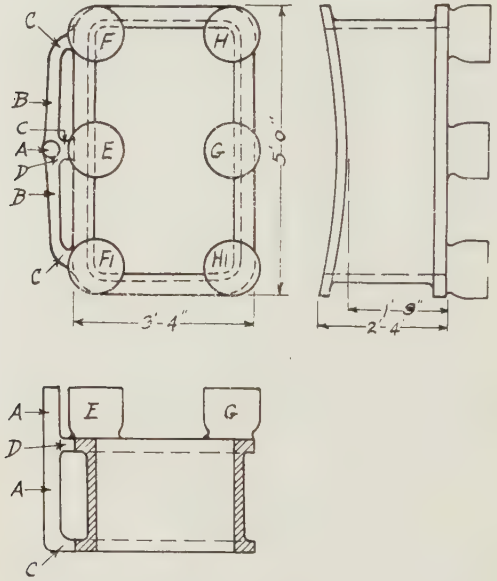

FIG. 1.—ORTHODOX METHOD OF GATING A TROUBLESOME CASTING.

A = Downgate. B, B = Crossgates. C, C, C = Ingates to lower flange. D = Single ingate to upper flange. E, F, F1, G, H, H1 = Feed heads.

in a horizontal position on the pouring floor and the casting was poured "flat." It should be noted that the upper ingate D is not a true "step-gate" and cannot exercise the devised function of promoting the selective flow of metal from the downgate into the upper levels of the casting. Without a "breaker-gate," devised to

check the downward velocity of the cast metal, such an ingate as D cannot reasonably be expected to function properly.

To overcome the deficiencies apparent in the castings made on the orthodox method, such deficiencies being attributable to the adverse temperature gradients in both mould and metal, and to the local " hot spots " at the lower ingates, promoting the formation of both external

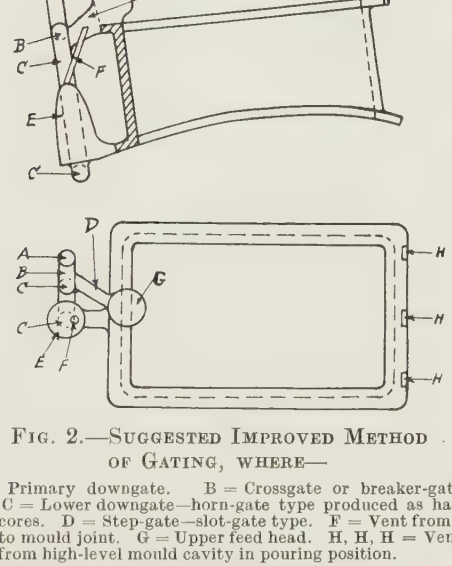

FIG. 2.—SUGGESTED IMPROVED METHOD OF GATING, WHERE—

A = Primary downgate. B = Crossgate or breaker-gate. C = Lower downgate—horn-gate type produced as half-cores. D = Step-gate—slot-gate type. F = Vent from E to mould joint. G = Upper feed head. H, H, H = Vents from high-level mould cavity in pouring position.

tears and mid-section cavity, the " partial reversal " method was used as described in other Papers by the author.[2] The method is indicated in Fig. 2, whereon the casting is shown in the pouring position, the mould being " banked " on a reversing block to an angle of 150 deg., the block being of such a height or thickness as will permit of " reversing " the mould through an angle of 30 deg., after pouring is completed, to produce an " angle of rest " of about 15 deg.

As the gating and heading system, illustrated on Fig. 2, may be somewhat difficult to understand, an additional explanatory diagram is provided in Fig. 3. The vent F is taken from the crown of the blind feed head E to the mould joint and the vents H, H, H, are taken from the mould cavity at locations which are the high plane of the casting proper, in the pouring position. It is essential that these latter vents be adequate to permit the egress of the atmosphere of the mould cavity at such a rate as will avoid developing any serious back pressure, which would oppose the inflowing metal; but, in ensuring such adequacy of aperture, it is necessary to avoid a shape of section which may promote a defect in the casting.

Rectangular Vents Advocated

Experience has shown that round vents, of sufficient diameter to evacuate the mould atmosphere at a proper rate, will frequently reveal an unsound spot—a fine pipe—in the casting when removed. Vents of rectangular section are greatly to be preferred, and the thickness of such vents should not be greater than one-half the thickness of the section upon which they are imposed. The thickness of the vents being prescribed by the casting, their width has to be determined in relation to the devised pouring rate to ensure that serious back pressure by mould atmosphere is not generated during pouring. Vent F is small, and may be of circular cross-section.

A comparison of the two methods of producing the casting, illustrated on Figs. 1 and 2, may best be made if one considers vertical sections of the casting, one for each method, comprising gate and head as well as casting. The casting as produced on the orthodox method is shown on Fig. 4.

Notwithstanding the provision of the step-gate C, it is affirmed that the casting, as shown on Fig. 4, would be almost entirely bottom-poured, provided that metal temperature and pouring rate were such as to run the casting

cleanly, without the formation of serious "cold shuts" or deeply penetrant ripples. In actual practice, metal was delivered at the downgate until a level was attained approximating the line X-X on Fig. 4. Pouring at the downgate ceased and feed metal delivered to the head by top-pouring directly into the feeder. (Reverting to Fig. 1, and continuing to describe actual practice, it should be stated that riser G was the first to be top-filled, pouring continuing until either the head was filled, or, if metal was flowing to the other risers, until a quantity had been delivered to G approximately equal to twice its capacity. Thereafter, metal was added, in turn, to each riser or feed head until all were filled. As a general rule, however, the metal was so cool at G, H, and H1, that G could be completely top-filled without promoting any rise of metal-level in the other feed heads.)

Most British foundrymen are likely to be acquainted with Brearley's graphic representation of the freezing of an ingot, inscribed lines approximately parallel to the mould faces being used to indicate the progress of the formation of the continuously-thickening solid envelope. The casting under discussion (Fig. 4) might be considered as a very poorly-designed ingot, parallel sided, and much too great in length—height, as poured—in relation to its diameter or section thickness. Added to this, there are the disadvantages to be associated with bottom pouring. This system of gating could not very well be entirely avoided, as the castings were necessarily produced in green-sand moulds.

Influence of Bottom-Gating

The bottom-gating of a casting inevitably produces an adverse temperature gradient in the metal, the top of the casting being coolest and the bottom being hottest at the moment the mould proper is filled. The amount of this temperature difference, and the "angle" of the temperature gradient, are related to the pouring rate—rise of metal in mould per second—and to the heat-conductivity of the mould. A slow

pouring-rate will produce a poor temperature gradient, as compared with that produced by fast pouring, when the gradient is indicated in the manner illustrated on Fig. 5. As the gradient line more closely approaches the vertical, for bottom-poured castings, the more favourable are the conditions for producing soundness by superimposed feeding heads.

It is not suggested that the gradient lines shown on Fig. 5 accurately represent the metal

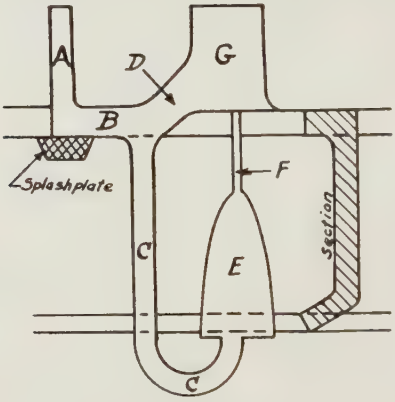

FIG. 3.—EXPLANATORY DIAGRAM OF FIG. 2, WHERE—

A = Primary downgate. B = Crossgate or breaker-gate. C = Lower downgate-horn-gate type produced as half-cores. D = Step-gate—slot-gate type. E = Lower feed head-blind. F = Vent from E to mould joint, and G = upper feed head.

temperature at the different levels of the casting, but the diagram is used—as the author has used it in discussions with operative foundrymen—to indicate the general trend of one effect of bottom-pouring.

The transfer of heat from the metal to the mould is the prime reason for the notable difference in temperature existent between the upper and the lower metal in the mould, and it is reasonable to believe that such transference of heat is, to some considerable degree, related to

the duration of contact of metal with mould in the act of pouring. It therefore follows that the lower levels of the mould, closely adjacent to the ingate, are considerably heated and delay the solidification of the metal. Hot spots, so generated, produced two types of defects on the casting under survey: (1) External hot tears

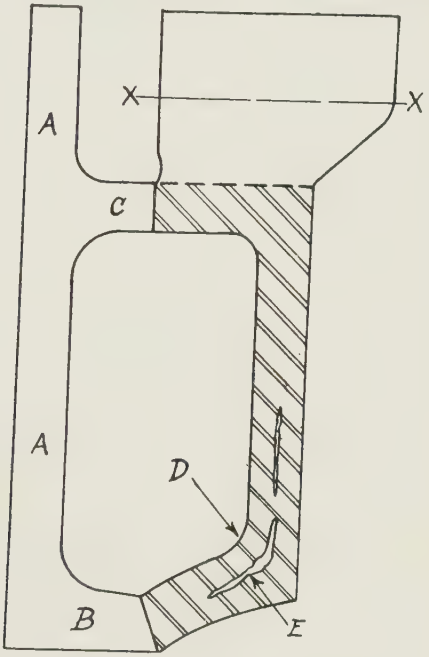

Fig. 4.—Showing Level of Pouring Height and Defects.

at the radius D, and (2) internal shrinkage cavities E (Fig. 4).

All the castings of this type, produced on orthodox methods (Fig. 1) showed these defects at each of the three lower ingates, and while external chilling at the radius eliminated or decreased the incidence of external hot tears, the

mid-section unsoundness persisted. Failure to deliver feed metal to the affected parts is believed to be a considerable factor in the combination of causes which promoted the defects.

The Partial Reversal Method

In the revised system of production the castings were gated and headed, and were poured on what is called the " partial reversal " method, as indicated on Fig. 2. It should be noted this method prescribes, as essential to its efficacy, that the castings be preferably gated and headed at one end of the long axis, whereas the castings produced on the orthodox method were gated at the side, or parallel with the long axis. Greensand procedure had to be followed, and the casting was, necessarily, bottom gated to provide for the introduction of the metal in a quiet, nonturbulent manner.

Horn-gating into the bottom of a side, or elbow, riser has distinct advantages over either the straight or the tangential ingate. In the particular case under discussion it had the added advantage of overcoming one of the deficiencies of the ordinary blind riser in that the " geyser " effect of the ingate almost entirely prevented the accumulation of relatively cool metal within the blind head.

Pouring Conditions Prescribed

The angle of pouring prescribed that at least two-thirds of the casting would be produced by metal flowing through the lower ingate, and the speed of pouring was steadily accelerated until it could be seen that metal was flowing through the upper gate. It is believed that, with the indicated gating system, metal ceases to flow through the lower gate almost immediately upon the commencement of delivery through the upper gate, and it therefore follows that the lower levels of metal quickly come to rest, and can proceed with solidification while the upper levels of the mould are being filled. The pouring rate must be such, as in the case of the

castings made on ordinary methods, that serious "cold shuts" or ripples are avoided.

On Fig. 6 is indicated the gating and heading system used on the "partial reversal" method. In comparing this with Fig. 4, it must be remembered that Fig. 6 shows the whole of the heading system, whereas Fig. 4 showed only one of the six risers. The two feed heads used on the partial reversal method weighed a little less than half the total amount of head-metal used on the ordinary method.

The actual gate apertures at the lower flange, as shown on Fig. 6, was 9 in. by $1\frac{3}{4}$ in., which ensured the entry of the metal into the mould proper without serious turbulence. The blind head, disposed immediately above the horn-type ingate, functioned as a balancer to avoid surging within the mould cavity. In visualising the flow of metal in the mould—remembering that the mould is inclined at an angle of 15 deg., the ingate being the low point—it can readily be seen that distribution from a single large ingate must produce practically identical temperature gradients in the lower levels of the casting on each side of the long axis. Vertically, there is a local adverse temperature gradient for approximately two-thirds of the height of the body end-wall adjacent to the gating and heading system; but, as the upper gate begins to function, this adverse temperature gradient in both metal and mould does not become acute.

Approximately one-third of the metal which forms the casting is delivered through the upper gate, the metal delivered by the lower gate tending to build up to an appreciable "head" within the mould above the lower ingate and balancing the pressure at the downgate. Without the "breaker" gate, the upper gate would be late in functioning, and a considerably more acute adverse temperature gradient would be produced adjacent to, and above, the lower ingate.

The upper ingate is definitely a "slot," and is inclined upwards to ensure a mild whirling

or eddying motion of metal within the riser. This device is calculated to prevent the formation of a cool upper layer of metal within the riser as the upper levels of the casting are poured. If an ordinary flat ingate is used at the base of the upper head, it is found that very little eddying occurs in the riser while the upper levels of the mould are being filled. Consequently, when both mould and riser are filled —the top of the riser, in the case under discussion, being several inches higher than the high point of the casting at the other end of the mould—there may be several inches of re-

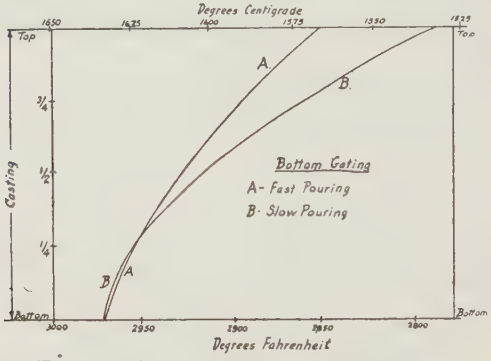

FIG. 5.—SHOWS INFLUENCE OF BOTTOM GATING ON TEMPERATURE GRADIENT.

latively cool metal at the top of the riser, lying over the hotter metal in the lower part of the riser. This is a local adverse temperature gradient which can be avoided by using a slot gate.

Pouring Details

The vents will seal themselves if they are of proper number, size and shape, and the mould may be " reversed " as soon as the ladle moves away. The mould is located approximately in balance on the rocking blocks or bar, and, the wedges being removed, may be reversed through an angle of about 30 deg. to produce an angle of rest of 15 deg. Moulds of considerable size

may be manipulated, but the larger moulds, containing castings weighing upwards of 26 cwts., usually demand the services of a crane.

At the "angle of rest," the casting is in the "feeding" position, where gravitation may amplify the effect of whatever favourable temperature gradient has been produced in pouring and reversing the angle of the mould. The adverse temperature gradient in the lower levels of the section shown in Fig. 6 is taken care of by the blind riser, which is placed in a superior position by the reversal of the mould, and by the favourable temperature gradient of the

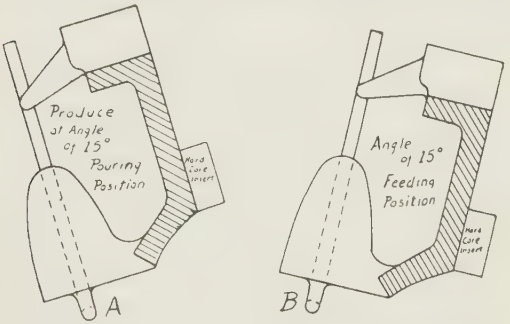

FIG. 6.—THE PARTIAL REVERSAL SYSTEM OF CASTING.

upper levels of the casting plus the superimposed feed head.

This casting taken, as an example for discussion at such length and in such detail, is not one which presents potentialities for the production of a perfect temperature gradient in both mould and metal, but it does present an opportunity for the citation of the successful application of the temperature gradient theory whereby controlled directional solidification was attained and commercially sound castings produced in a foundry which theretofore had experienced some considerable trouble and loss in making such pieces.

It might be argued that, if the heading and gating system used on the partial reversal

method had been employed along with orthodox "pouring on the flat," the temperature gradients requisite to the production of a sound structure would have been secured without the trouble of "reversing" the mould. Such an argument seems cogent, but it can here be stated that the argument was advanced and the method tried. It was not entirely successful, and it was demonstrated that without the reversal method larger feed heads were required. Even with these larger heads the body wall section adjacent to, and above, the lower ingate was not as sound as when the reversal method was used.

The Total Reversal Method

In steel-foundry practice the most favourable temperature gradient in both metal and mould may be attained by a system of operation that has been called "the total reversal method." Within limitations prescribed by the available equipment this method is productive of very definite economies, on certain types of castings, and at the same time promotes a degree of integral soundness of structure unattainable by ordinary methods.

The example chosen for description is a liner of the design shown on Fig. 7. Normally, such a casting—which has to be machined all over and must also be of uniform internal soundness—would have to be made pronouncedly tapered in section, tapering from heavy section at the top to light section at the bottom. Such a provision would, in turn, demand additional expense in machining off the excess metal.

The casting, as shown on Fig. 7, is a hollow cylinder having almost uniform wall thickness from collar to end. The feed head is annular in form and the gating system is produced in two cores. The upper core, in the pouring position, provides ten ingates, while the lower core contains the annular distributor gate, which is connected to the base of the downgate by a double cross gate. The downgate is either tile (stopper sleeves may be used) or is made of

special cores. A solid pattern, with feed head pattern and the print for the gate cores firmly attached, makes practicable the very simple one-part moulding method.

After the pattern is drawn, the mould cleaned, the centre core inserted and the gate cores positioned—these acting as centralising cores for the centre core—a baseplate is firmly clamped on, and the mould turned over into the pouring position, as shown in Fig. 7. As the mould is to be completely reversed after pouring, it is necessary to affix a cover plate or board. This must be provided with holes or slots to allow free venting of the mould atmosphere. The pouring operation—predicated by experience—applies metal as hot as practicable and a pouring rate as slow as practicable. These provisions produce in metal and mould the greatest practicable temperature gradient which, after the mould is reversed through an angle of 180 deg., bringing the head into its proper position to deliver feed metal, presents a metallurgical picture akin to that of a tapered ingot—big-end up—in a well-designed ingot mould provided with a hot-top or brick head.

With the casting in the reversed position after pouring, the lower levels of the metal are cool, and are in contact with cool mould, while the upper levels, particularly in the head, will be maintained in a fluid condition for a considerable length of time by reason of the heat of the mould with which they are in contact. In constructing a diagram to indicate the progress of solidification for such a casting in such a mould, using Brearley's method of inscribed lines, the lines would not be drawn parallel with the mould faces, but would, rather, incline toward each other as in an elongated V.

Temperature Gradient for a Liner Casting

Fig. 8 presents as a full line a hypothetical temperature gradient for the example under discussion, the line sloping downwards from left to right, such inclination being indicative of substantial feeding potentiality by the superimposed

"riser." The broken line on the same figure is a hypothetical temperature gradient for the same casting bottom gated at the light section, with the collar or flange and the feed head at the top. In attempting to produce such a casting in such a manner it is to be assumed that a fairly rapid pouring rate would be ensured and that the metal temperature would not be unduly high.

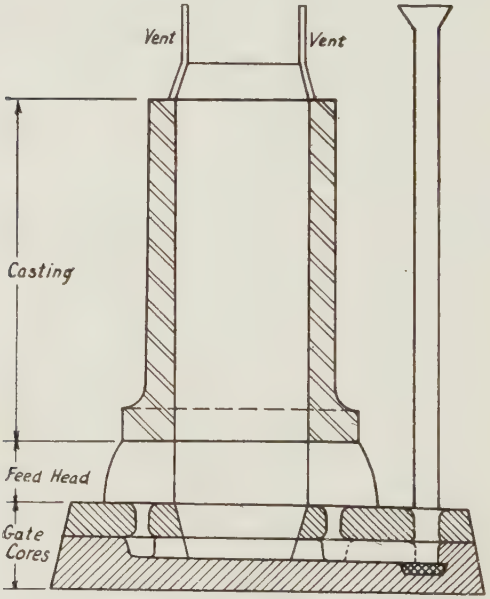

FIG. 7.—LINER CASTING LENDING ITSELF TO THE TOTAL REVERSAL METHOD.

Admittedly, Fig. 8 is conjectural, but the suggested gradients are based upon observation of the pouring of many castings and the examination of a number of castings which have been "bled," either intentionally or fortuitously. In scrutinising the temperature gradients it is not to be assumed that anything but an average for the section is intended to be expressed. It is recognised that a temperature gradient exists

from surface to midsection and, in a horizontal direction, from gate to parts remote from the gate in castings which are poured " on the flat."

The temperature gradient of the mould—really a relatively thin envelope of mould surrounding the casting—is much more difficult to visualise. Briggs and Gezelius[1] have shown that throughout a considerable part of the cooling of a cast 6-in. dia. sphere the temperature of the sand at a distance of $\frac{1}{8}$ in. from the mould-metal interface was only about 150 deg. Fah. less than the temperature at the centre of the sphere.

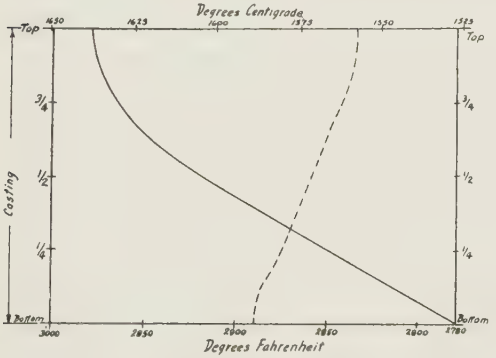

FIG. 8.—A HYPOTHETICAL TEMPERATURE GRADIENT CURVE FOR THE CASTING SHOWN IN FIG. 7.

Despite the low thermal conductivity of sand, the mould takes a considerable amount of heat from the metal in transit, as is demonstrated by castings accidentally " bled " as the result of a break-out near the gate. Such remanent shells show an envelope of considerably greater thickness formed at the upper levels than at the lower levels close to the ingate, and demonstrate the potency of the mould as a coolant in relation to pouring temperature, pouring rate and section thickness.

It is obvious that the potency of the mould as a cooling agent decreases sharply as section

thickness increases, but the potency of the mould increases as the distance to be traversed by metal within the mould increases. Thus, the temperature gradient which can be created in a cast 6-in. cube, suitably headed, is very slight as compared with that attainable in a cast piece 6 in. by 6 in. by 72 in. long produced on the partial-reversal method. (For detailed descriptions of various mould manipulative methods, partial and total reversal, the reader is referred to previously published Papers by the author.[2])

American and British Practices

In discussing temperature gradients, the author has adhered to examples of castings made under conditions which largely govern American practice. In that country little or no moulding material is used that has the characteristics of either the British " compo " or the Continental European " chamotte," and it is fairly general practice to gate into the lower levels of the mould. Top-pouring such as may be adopted with " compo " moulds is relatively rarely used in American foundries.

The temperature gradients in mould and metal which may be created by top-pouring are more favourable than those attainable by bottom-gating unmanipulated moulds, but are not as favourable as those to be achieved by bottom gating and " reversing " the mould after pouring is completed. A fine example of good gating method is provided in Hatfield's Paper[3] delivered to the American Foundry Convention in 1934. The heading of the casting is also very interesting, as it shows an appreciation of the necessity for a large volume of feed metal when blind risers are used which are not directly served by ingates. The filling of such risers produces in them—as it does in ordinary open heads which are not filled from the top—an adverse temperature gradient in both mould and metal. It is, therefore, necessary to have risers of such dimensions, in relation to the sections with which they are connected, that their reserve

of temperature is adequate to maintain fluidity of their interior metal over a period of time sufficient to ensure the solidification of the casting; or, at least, of that part of the casting which each riser is devised to feed.

Design and Manipulatable Moulds

The temperature gradients in a bottom-gated casting are bound to be adverse, and only a locally favourable condition can be created by top-filling the feeding heads. Reverting to the part of a casting shown on Fig. 4 and including the feeding head, a temperature gradient of the type postulated in Fig. 9 would probably be produced a short time after pouring was completed. The local favourable temperature gradient within the feed head will ensure that the casting proper immediately below the riser will appear sound when the head is removed, but the adverse nature of the temperature gradient for the lower three-quarters of the height of the casting—amplified by the adverse temperature gradient of the mould, resultant upon bottom-gating—points to the conclusion that the casting cannot be expected to be free from mid-section unsoundness in the lower levels. Thus it must be realised that design is a factor of very great importance and that for castings produced in unmanipulatable moulds—moulds that cannot be " reversed " after pouring—the taper or " wedge " type of section, small end down, should merit the attention of designers as being complementary to the production of integrally-sound cast structures.

In castings which are of a size that can be produced in manipulated moulds—using one of the reversal systems—there does not exist to the same extent the necessity for tapering-wall sections, the creation of favourable temperature gradients in both mould and metal being competent to overcome, to some considerable extent, the normal difficulty of feeding a section. There is, however, very definitely a limit to what can be done by mould manipulation, this limit being prescribed by practicable pouring temperature and pouring rate.

One of the features of promoting controlled directional solidification, as the result of properly-organised temperature gradients, which appeals to the steelfounder is the economy of feed metal. It is admitted that the discovery of the extent to which this economy could be carried was accidental—but for the accident, unnecessarily-large feeding heads might have been continued in use—and that the early applications of mould reversal were successful attempts to cure defects which were apparent in certain castings immediately the risers were removed. The temperature-gradient theory is built upon

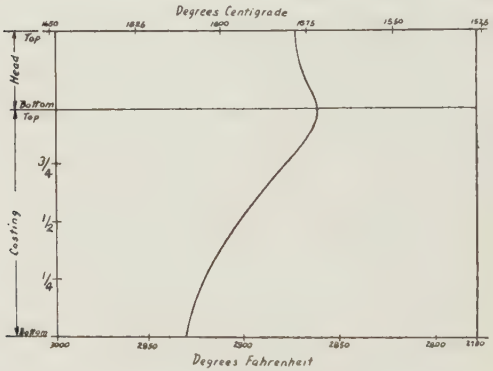

FIG. 9.—TEMPERATURE GRADIENT IMMEDIATELY AFTER CASTING.

the practical results arrived at by manipulating moulds after pouring is completed, is applicable with beneficial results to castings made in moulds that cannot be so handled, as it leads the practical foundryman to a more correct appreciation of the functions of gates and heads.

A system of step-gating may be considered as being of less efficiency than mould reversal, but more efficient than bottom gating, in promoting soundness of cast structure.

Chills and Controlled Directional Solidification

The concept of perfect progressive solidification, from bottom to top in orderly continuity, is

one that must be discarded, because of its utter impracticability; but controlled directional solidification is, for certain types of castings, an implement available to the founder. The means described[2] for achieving the desirable condition by "reversing" moulds or by a good system of gating and heading must be amplified by "chilling" isolated masses, pads, or bosses that cannot conveniently be reached by feed metal. For reasons which are apparent to most practical steel foundrymen, the author disapproves the use of internal-chills—variously described also

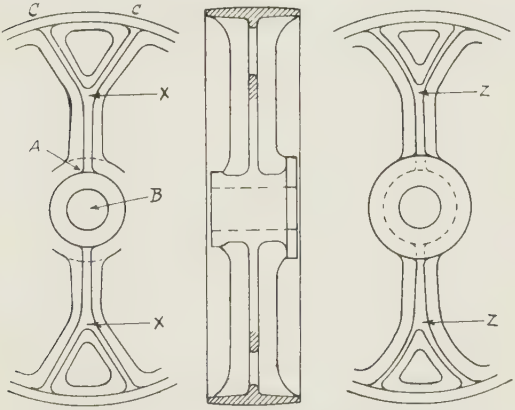

Fig. 10A. Fig. 10B.

Figs. 10A and 10B.—Lorry-Wheel Design of the Y Type.

as residual, cast in, remanent—in locations which can effectually be treated by external chills. It is conceded that in some instances an external chill cannot be used, and that nothing but an internal chill will achieve the desired result.

In promoting controlled directional solidification, external chills can be made to function efficiently upon parts that could never be adequately dealt with by internal chills, and this without the dangers of blows and the heterogeneities resultant upon the use of cast in denseners. The designing, as to shape and

weight, of external chills in relation to the parts upon which they are imposed is an infant art, but is one which will be developed to the benefit of both castings and founders. The shape of the chill must be such that it will not promote a sharp line of chill effect. It should be devised to take care of that excess of cast metal which is imposed on the general structure as a boss or pad without interfering with the whole projected scheme of solidification. If the chill be excessive in its effect, it may tend to negative other means taken to ensure an ordered and progressive solidification by closing the avenue through which feed metal should reach other parts of the casting.

The weight of the external chill must be related to the amount of heat it may have to take up from " metal in transit " as well as to the amount of heat it is devised to take from the " metal at rest " when the mould is full. It seems probable that the designing of efficient external chills will be arrived at empirically, and will be an art for some considerable time before sufficient fundamental knowledge is amassed to warrant precise scientific definition.

While chilling may be used to mitigate the dangers attendant upon concentrations of metal which cannot be fed from risers, the fact remains that the designer can, if willing, do much to eliminate the necessity for such costly foundry expedients. Heuvers[4] has suggested variations from orthodox practice in design which make a distinct appeal to the steelfounder, but it must be remembered that some inescapable features of design tend to create " hot spots," which, in turn, tend to promote either internal cavities or externally visible tears, or both.

Hot Spots

The founder rightly insists upon radiused junctions where two sections of metal would, otherwise, produce sharp corners or angles of sand projecting into the metal. The imposition of the fillet produces a local concentration of metal that must either be fed or chilled to ensure

complete soundness. Internal hot tears or enclosed pipe are evidence that " humps " have occurred in the temperature gradient—if it was generally of a favourable type—or that the temperature gradient was generally of an unfavourable nature.

" Hot spots " are most likely to form at the ingate. Simple modifications of gate design appear, superficially, to cure the trouble, but it must be said that in many cases the " cure " is more apparent than real. The casting merely appears to be sound on the surface when the gate is removed, yet there may be a mid-section unsoundness. Such a localised deficiency may be a commercial defect in certain types of castings, whilst in others it is a metallurgical defect of no serious commercial significance.

On many types of castings, poured in the orthodox way, it is easy to locate the hot spot outside the casting by gating into a main riser. Valve bodies and flanged fittings have a pronounced tendency to exhibit leaks either at the radiused junction of flange and body or at a bolthole when gated at the edge of a flange. This bespeaks, of course, a crack or tear which extends to the bore of the casting. Such a tear or crack is due to a gate hot-spot, and the trouble can readily be cured by gating into the base of a lumped riser —sometimes called a face riser or elbow head—on the face of the flange. Such a riser should be at least twice as thick as the flange upon which it is imposed, in order that the centre of the mass—the last to solidify —is outside the casting. This procedure may necessitate longer coreprints than are normally provided, but the small expense of alteration to pattern and corebox is generally a good investment.

Box-like Castings

The tendency of box-like cast structures to tear at the corners is well known, and this tendency persists, even though the metal section is uniform, the external contour paralleling the internal radius. In such an example is demonstrated the effect of disproportion of metal to

sand. The corner or " angle " of sand, even though apparently suitably radiused, is heated on two sides; it is subject to nearly twice the thermal attack that is imposed on the sand forming plain faces and it cannot take heat from the metal at the same rate as does the sand in contact with plain plates of metal.

Every so-called internal angle is, therefore, potentially a hot spot. These local humps in the general temperature gradient may generally be avoided by face-nailing the fillets, but a nice discrimination is necessary in prescribing the amount of such chilling. By " face-nailing " is meant the use of short, flat-headed nails, inserted until the heads are flush with the mould face. The heads do not project into the casting to become, thereby, internal chills. The application of this simple remedy is not always practicable because of pattern construction.

Mould Effect

Thus far the author has treated the subject in relation to the influence of gating and heading methods, together with mould manipulation, in promoting soundness in the cast structure which, in other words, is freedom from external tears and internal shrinkage cavities. It appears desirable to emphasise the effect of the mould—which is affected by metal in transit—upon the progress of solidification of the casting, because the literature pertaining to the production of steel castings has, hitherto, hardly touched upon the matter.

The extent of this effect is demonstrated by castings produced on one of the reversal methods where, by mould manipulation, the temperature gradients of both mould and metal are disposed in the correct direction.

At temperatures above the liquidus, steel is believed to behave as a true liquid, and McCance[5] gives the figure 0.00039 contraction per deg. C. It therefore follows that if what are ultimately to become the upper levels of the mould can be considerably heated by the relatively slow pouring of hot metal at a rate which, while sufficient

to ensure a cleanly-run casting, considerably cools an appreciable amount of the metal, the mould is made to conserve heat in a graduated manner and control, directionally, the solidification of the casting.

Such conservation of temperature, particularly in the heads of totally-reversed castings, will, despite the high temperature of the upper levels of metal, result in adequate feeding from a relatively small reservoir or feed head. Cases have been noted where risers delivered as much as 35 per cent. of their volume to the casting,

FIG. 11.—DILATATION CURVE OF THE STEEL USED FOR MAKING THE CASTINGS SHOWN IN FIG. 10.

this being approximately equal to 3.5 per cent. of the volume of the total metal in mould. This figure of 3.5 per cent. is somewhat higher than the average contraction, measurable as pipe, in castings examined by the writer. To state the matter in another way, certain castings have been produced, ranging in weight from $1\frac{1}{2}$ to 9 cwts., with a discard of only 6.5 per cent. Admittedly, these castings were made on the total-reversal method and every precaution was taken to promote conditions that would give a high yield, yet it may be said that castings of

a similar type and larger in size were consistently made on the partial-reversal method, with an average yield of over 85 per cent. of metal in mould.

Post Solidification Temperature Gradient

The temperature gradients in castings at temperatures below solidification point must be a study separate from the matters discussed in the foregoing part of this note. Cold cracking is probably more to be associated with design than with moulding and pouring procedure. This statement is made because some designs have been noted which consistently developed such stresses in the castings as to lead to a considerable proportion of loss by cold cracking, but only small losses by hot tearing.

Fig 10A indicates the design of a truck wheel which was common a number of years ago, in the era of the solid-rubber tyre. Fig. 10B shows the modification of spoke design which overcame the trouble of cold cracking of the spokes. It should be noted that the only modification was the alteration of the shape of the spokes, the hub and rim remaining the same in both designs. The spokes, six in number, are of cruciform section, Y-type, and split to give twelve junctures with the rim and mid-web. In the straight Y-type, Fig. 10A, these junctures were equally spaced. In the curved Y-type (Fig. 10B) the distance across the top of the Y was slightly greater than the distance between the tips of two Y's.

The wheels were gated at the hub, thus ensuring that the casting was gated into its heaviest section, and also that distortion was reduced to a minimum by providing that the metal at any two or more parts of the casting equidistant from the centre be of the same temperature, or as nearly so as possible, at the moment the mould is filled. This provision seems necessary on such castings as truck wheels, which are of light general section and which must be as nearly as possible in balance after machining. It is not so important on heavier castings such as gear blanks.

The chief trouble experienced in the production of the wheels having the straight Y-type spokes was a pronounced tendency to cold-cracking either at the points marked X or at A (Fig. 10A). Relatively few of the castings failed by reason of hot tears at these locations, and the magnitude of the residual stresses obviously varied in different castings. Some would cold-crack during cleaning operations, and the practice of heat-treating—a straight normalising—before fettling did not entirely eliminate the trouble. As a matter of fact, a number of fully-machined castings were known to develop the characteristic crack in transit, by rail, from foundry to customer.

It is believed, by the author, that the tendency to crack was increased by machining, the removal of metal from the face of the tread and from the bore adversely affecting the residual stresses which, previous to machining, were not so remote from equilibrium as to promote a crack. This detail will not be discussed at length in the present Paper.

A scrutiny of the defective castings showed that in an overwhelming majority of the examples, a crack occurred at or near a point of metal concentration. Any deviation from the practice of gating at the hub aggravated the trouble, as well as introducing other deficiencies.

Visualising the temperature gradients—in this case, horizontally from hub to rim—it is apparent that at the moment the mould is filled the hub consists of the hottest metal contained in the hottest part of the mould. As the distance from hub increases, the temperature of both metal and mould decreases. While this is satisfactory from the viewpoint of securing adequate feeding from a riser imposed on the top of the hub, it has certain adverse implications when the design is studied in relation to dilatation phenomena. A dilatation curve, typical of the steel in which these castings were produced, is shown in Fig. 11.

Remembering that pronounced temperature gradients, correctly disposed for feeding, exist

in both metal and mould, and that the metal temperature at the hub is probably at least 66 deg. C. higher than at the rim, solidification—and subsequent cooling—proceeds selectively from rim to hub. The rim, being in contact with cool mould, cools down relatively rapidly, and, down to 840 deg. C., is constricting. In the early, and most rapid, part of this period the hub and the inner ends of the spokes are conceivably so hot as to respond readily to the stress without incurring any pronounced residual influence. At a later stage in the cooling of the casting the rim will be passing through the range 840 deg. C. to 680 deg. C., and will be expanding while the inner parts of the casting—hub and parts of the spokes—are constricting and contracting. It was in this thermal period that the few cases of hot tears at A (Fig. 10) were believed to be generated.

The significant points to be considered, in relation to design, are marked XX on Fig. 10A. All the way down to shop temperature the rim precedes the remainder of the casting in cooling, and in aggregation of strength down to the lower end of the blue-brittleness range. The points XX—and similar locations diametrically opposed on the other spoke—became practically fixed points in their relation to the rim at CC, while the distance between them should decrease with falling temperature.

Thus, in the later stages of the cooling of the casting, the spokes were placed pronouncedly in tension of such magnitude as to lead to cold-cracking in far too many instances.

It became apparent that the prime necessity was to permit the points XX to move closer together in as full accord as possible with the normal uninterrupted contraction of cast steel. The design was accordingly modified to produce what is shown on Fig. 10B. The head of the Y, Fig. 10B, is produced as two curved members, each of which is of lighter section than the single member of the Y.

Given the same temperature gradients as the casting of the straight Y type, the points ZZ could get closer together, the curved spoke-

members deforming under the tension of the contracting "inner" parts of the casting. To avoid any misconception, it should be stated that the curved spoke-members were of the same cross-section as those of the relative parts of the straight Y-spokes. The ability of the curved upper members to straighten—that is, to assume a larger radius—entirely eliminated the cold-cracking trouble, as well as the more rare occurrence of hot-tearing at the junction of a spoke with the hub.

This is the only example of design modification that the author proposes to submit in relation to the prevention of cold-cracking. Others could be cited, and it is believed that most practical foundrymen could, from the wealth of their experience, quote instances of difficulties encountered. It is hardly possible to entertain the hope that all such difficulties could be overcome in a manner so simple as that which effected the cure in the case of the lorry wheel.

No attempt will be made by the author to summarise, as it is his opinion that the matter is too complex—despite the simple examples chosen for discussion—to admit of comprehensive accuracy. It is to be remembered that each casting presents its own peculiar problem and, while castings may be classified in types, seemingly small variations affect materially the classification.

For inability to clothe the concepts in words that will be explicit to all, the author tenders his apologies, and undertakes to deal—within his limitations—as fully as possible with the matters that are bound to arise in the discussion.

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SOME NOTES ON INGOTS MOULDS

By T. Swinden, D.Met. (Member), and G. R. Bolsover, F.Inst.P.

Mould Costs

By far the greatest proportion of the world's steel production is cast in the form of ingots for subsequent manipulation by rolling or forging. A very rough estimate indicates that the annual consumption of ingot moulds is of the order of 100,000 tons. Practically the whole of this is in the form of cast iron, and therefore the subject is of considerable interest to the ironfoundry industry. At the same time, it is necessary to keep in mind that the ingot mould is merely a tool required to give the desired shape to the steel ingot, and its value is to be considered under two headings: (*a*) the cost per ton of steel produced, and (*b*) the influence of factors connected with the mould on the quality of the resulting ingot.

As regards the cost per ton of ingots, in a recent Paper by Mr. J. Blakiston, before the Middlesbrough Branch of this Institute, it was stated that the value of castings of all kinds used in the ultimate production of a ton of semi-finished steel was approximately 10s. per ton, and that the ingot moulds, bottoms and slag ladles accounted for from 2s. to 5s. per ton.

Confining attention to ingot moulds, F. W. Morawa ("Stahl und Eisen," 51 (1931), Vols. 40 and 41, pp. 1221-28 and 1256-63) stated that the cost of moulds represented only some 3 per cent. of the cost of conversion in the steelmaking shop, which conversion cost represented about one-fifth of the total cost of the ingot. In the authors' opinion these values are very approximately correct. The ingot mould costs in the plants of the United Steel Companies, Limited, varied in 1934 from 9d. to 1s. 7d. per ton, according to the type of plant and steel being produced. The cost of bottoms varied from 1½d. to 4½d. per ton.

As a further approximate guide on this subject, if it is assumed, say, for rolling ingots that the weight of the mould is similar to that of the ingot produced and present prices for ingot moulds and mould scrap are accepted, then it can be estimated that if the mould gives a life of 40 casts, the cost per ton of ingot will be about 1s. 6d. per ton. If the life be 80 casts, the cost will be 9d. per ton, if 100 casts 7.2d. and if 200 casts 3.6d. These figures are not strictly accurate because other costs are involved if moulds give a short life, but it is sufficient to indicate that if, for example, the life of an ingot mould can be increased from 100 to 200 casts, other things remaining equal, this represents a possible economy to the steelmaker of the order of 3½d. to 4d. per ton.

It is necessary to recognise, therefore, that the possible improvements that can be made have a limitation in the value of the possible savings, and, as will be referred to later, the influence on the quality of the steel ingot produced is of greater importance than the saving to be achieved by increasing the life of the mould. At the same time it should also be noted that, taking an approximate figure of 7,000,000 tons of ingots produced annually in this country, an economy of 1d. per ton represents nearly £30,000 per annum.

Sufficient has been said perhaps to establish some idea of the value of this service to the steelmaker so far as the life of the ingot mould is concerned.

Mould Lives

The first essential in assessing the value of ingot moulds is to have an accurate system of recording data. In works of the United Steel Companies, Limited, it has been the custom for several years to keep a complete record of the life of every mould so that the results can be analysed by "maker," "size," "type," "composition," etc., and as regards the moulds which are made within the organisation, additional data as to iron mixture, cupola practice, casting temperature, analysis, etc., are tabulated.

Each month is recorded the life of every mould scrapped during that period, the cumulative average for the period is reported and also the average for the preceding half year. In Table I are given the six monthly average figures for a selected number of mould types at the various branches. The description will probably be sufficient to indicate to those interested the type of mould referred to, but if required the authors will be happy to provide actual sketches of each of the moulds in question. An analysis of these figures produces some interesting observations. It is seen that over a period of time in some shops the lives vary to a considerable extent, although it may be said, speaking generally, that there has been a general trend towards improvement; in some cases this has been quite marked. There are cases where one make of mould during a certain period has given consistently low results, while another make of similar mould has given much better results. This definitely indicates that the quality of the mould is primarily responsible. On the other hand, it will be noted that in certain periods there has been a tendency for all makes of moulds to give lives lower than average, and the general explanation in such cases is to be found in a change in shop conditions necessitating using the moulds with greater frequency. The authors have carried out specific experiments on this point and the indications have been that conditions which reduce the temperature to which the moulds are heated have a definite tendency to improve their life.

It is not proposed to enter into a closer analysis of these figures at the moment, but it is suggested that they will provide a useful basis for discussion and a valuable record in that they do represent carefully-recorded figures in a series of six melting shops operating under different sets of conditions. For the benefit of those who may not be conversant with the various plants, it may be stated that the Frodingham and Appleby branches are engaged primarily in the production of mild basic structural steels. The

figures for the Templeborough branch relate essentially to mild basic steel but with a proportion of high-carbon steel. The ingots at the Rotherham branch are of acid steels of high-carbon and alloy quality. The Workington branch make acid-Bessemer steel of various types, while the values from the Fox branch relate to acid and basic open-hearth steel, mainly of alloy and special qualities. No values for electric steel are included in these figures.

It is at once recognised that such figures must depend to some extent on the type of steel being made and also to a considerable extent on the way in which the moulds are used. As regards the influence of the type of steel, it is known that mild steel and particularly free-cutting steel is more severe on the mould than higher-carbon steels, but, on the other hand, it is essential that the mould should be in first-class condition when casting expensive alloy steels, and a mould would be discarded from a shop making such steels at an earlier point than would be the case in a shop making, say, mild structural steel.

The value of a good mould in producing better-quality ingots is far greater than the intrinsic value of increasing the number of lives within the range that at present appears possible.

Influence of Mould Metal on Mould Life

One ought perhaps to state first personal ideas concerning the mechanism of breakdown and type of failure which ultimately determines the life of the mould, but it has been decided instead to present some data concerning the influence of composition and deal with these other items later.

The authors propose to confine their attention meantime to iron moulds, and it is the fact that at least in many works hematite iron has been specified, having in mind the higher salvage value of the used moulds. Nevertheless, it has been suggested that a fairly pure hematite was a good choice apart from this, on account of its high resistance to thermal shock. It is not necessary, at a meeting of foundrymen, to outline

the influence of the various elements normally found in hematite iron and describe the effect of the various elements on the structure and properties of the material. The authors have found —and this experience is, it is thought, in full accord with that of many other observers—that the composition can vary within fairly wide limits without any consistent effect on the mould life. In other words, moulds having abnormally good and abnormally bad lives are found to differ only very slightly in chemical composition. Far more importance is no doubt to be placed on the structure of the material, with particular reference to the form and distribution of the graphite carbon.

The authors have noted with interest the recent work of the Cast Iron Research Association in this direction, and look forward with great interest to the result of practical tests on the special type of iron which now promises to become available, having a high total carbon, a considerable proportion of which may be graphitic, but in a very fine and evenly-dispersed form throughout the structure.

Uniformity of structure is no doubt also a very important matter, having in mind that a large proportion of moulds fail by cracking long before the surface is sufficiently deteriorated to warrant the mould being discarded.

A general statement of the analysis of the moulds that have been used by this company would be as follows:—Total carbon, 3.5 to 3.75; combined carbon, 0.3 to 0.6; manganese, 0.6 to 1.0; silicon, 1.9 to 2.3; sulphur, 0.03 to 0.05; and phosphorus, 0.03 to 0.045 per cent. There is a tendency at the present time to work towards a rather lower silicon, say 1.7 to 1.9 per cent., with manganese higher at 0.9 to 1.1 per cent. It is also a matter of uncertainty whether the low phosphorus previously specified is best from the point of view of mould life, some evidence being provided that a rather higher phosphorus, say 0.06 to 0.08 per cent., is to be preferred. In this direction it will be noted

that some German moulds contained phosphorus in the region of 0.2 per cent.

Alloyed Cast-Iron Ingot Moulds

It is interesting to note that none of the special heat-resisting qualities of cast iron has fulfilled the early expectations that they might provide super-quality ingot moulds. There are still differences of opinion as to whether some of the low-alloyed iron moulds are worth while. Personal experience so far has been rather mixed, but, on the whole, the authors would say that they have no evidence to show that the addition of chromium or nickel is worth while. In one series of tests the addition of 0.5 per cent. chromium at Stocksbridge showed a definite improvement on 13 moulds, the average life being 63, as against an average of similar moulds without chromium of 45. A further set of moulds, having additions respectively of 0.25, 0.5 and 1.25 per cent. chromium, did not confirm the earlier results. Batches of experimental moulds containing 0.5 per cent. chromium were used at Templeborough and at Frodingham. The final reports were that there was no improvement in the life of the moulds.

Experimental batches of moulds containing 1.0 per cent. nickel showed no advantage; in fact, the results were inferior to those of the standard composition. There is, however, some indication that somewhat higher manganese would be advantageous, and moulds containing $1\frac{3}{4}$ per cent. manganese are under test at the present time.

The authors have examined the influence of the admixture of steel scrap, and also the influence of the proportion of scrap mould metal used. No advantage was gained by the admixture of steel scrap except in so far as this may be used to regulate the content of silicon. A careful series of tests on the use of mould metal indicates that under one condition of manufacture the best results were obtained with an admixture of 30 per cent. of mould metal.

TABLE I.—*Six Monthly Average Lives of Ingot Moulds at the Various Works of the United Steel Companies, Ltd.*

Type of mould.	Branch.	Maker.	To Dec., 1934.	To June, 1934.	To Dec., 1933.	To June, 1933.	To Dec., 1932.	To June, 1932.	To Dec., 1931.	To June, 1931.
70-cwt. Tapered top	Frodingham	D	105	97	126	134	128	116	122	—
,, ,, ,,	,,	E	—	79	92	110	126	113	—	—
,, ,, ,,	,,	F	100	88	118	98	101	92	90	—
,, ,, ,,	,,	G	89	80	97	125	115	89	81	—
,, ,, ,,	,,	C	93	80	104	106	105	—	—	—
80-cwt. Tapered top	,,	G	93	—	—	—	—	—	—	—
,, ,, ,,	,,	C	51	49	73	65	—	—	—	—
70-cwt. Brick top ..	,,	D	98	99	28	—	—	—	55	—
6-ton ,, ,, ..	Appleby	G	45	31	17	11	—	—	—	—
6-ton Long tapered top	,,	C	83	62	—	26	—	—	—	—
6-ton Long tapered top	,,	G	—	—	39	32	35	41	40	25
6-ton Long closed top	,,	G	72	79	39	—	—	—	—	38
6-ton Long closed top	,,	E	83	70	32	—	—	—	—	41
10-ton Long closed top	,,	D	84	71	20	—	—	—	—	—
10-ton Long closed top	,,	E	65	58	42	—	—	—	—	38
10-ton Long closed top	,,	G	82	67	—	—	—	—	—	—

10-ton Brick top ..	,,	D	53	37	—	—	—	—	—	—
,, ,, ,, ..	,,	E	28	42	30	30	—	—	16	—
15-ton Rammed top	,,	G	62	54	56	47	43	46	49	41
21-in. S.C.T.	Temple-borough	B	83.22	87.23	72.75	74.30	76.42	85.8	85.4	82.4
,, ,, ...	,,	G	76.77	77.61	82.69	81.03	80.90	89.7	96.0	79.0
,, ,, ...	,,	F	99.00	97.93	86.59	92.82	84.56	—	—	70.5
,, ,, ...	,,	H	79.00	90.27	79.68	76.05	—	—	—	—
,, ,, ...	,,	C	77.57	78.02	—	—	—	86.0	95.0	78.0
11-in. Octagon ..	Rotherham	B	52.66	33.33	50.00	53.0	30.4	29.29	42.5	43.6
17-in. sq. Centre run	,,	B	41.89	45.85	42.63	43.88	38.8	40.3	45.33	46.4
18 × 19-in. Closed bottom	,,	B	68.43	57.54	59.50	48.0	47.0	36.2	53.25	53.1
14 × 12-in. Sided open ended ..	,,	B	41.40	34.43	46.70	49.48	30.12	—	—	—
19 × 12-in. Sided open ended ..	,,	B	46.51	56.56	47.92	45.20	19.0	—	—	—
19½ in. Sq.	Workington	C	—	54.23	43.63	54.27	45.5	—	—	—
21 × 19¼ in.	,,	C	—	64.84	58.15	55.23	—	—	—	—
26-cwt. Plug	Stocksbridge	A	40	37	33	32	30	37	35	13
38-cwt. Plug and recess (long) ..	,,	A	47	41	43	48	59	53	—	—
38-cwt. Plug and recess (short) ..	,,	H	38	39	—	—	—	—	—	—
43-cwt. Recessed ..	,,	F	—	39	40	—	30	19	—	20
58-cwt. Plug	,,	F	29	30	29	—	—	—	—	19

Where no figures are inserted, either these particular moulds were not in regular use at the time, or the records are incomplete.

Extensive trials have also been made comparing cupola-melted iron with a mixture of mixer metal and refined iron. The latter proved to be somewhat superior, but moulds made from all refined iron were no better than the standard cupola iron. The use of molybdenum has been advocated, but no convincing results are yet available. The same applies to certain other special alloys which naturally arise in one's mind.

The above comments are necessarily somewhat brief and sketchy, but they do tend to indicate what is felt to be the right line of progress, namely, that a most satisfactory and economical mould will be one which does not depend essentially on the addition of expensive special alloys, but on obtaining the correct structure in a suitable hematite iron. The subject has, of course, been referred to by many other writers, but it is not proposed to give a lengthy statement of other published data. The subject is having the attention of the Heterogeneity of Steel Ingots Committee, and has been referred to in several of their reports. Morawa (*loc. cit.*) makes a useful contribution to this subject, and Table II is reproduced from this Paper. In the recent Paper by Blakiston (*loc. cit.*) one is again told that, after the careful observation of over 250 moulds, it was found that the analysis, within reasonable limitations, had no influence on the subsequent life of the mould. Moulds of identical analysis gave 13 and 120 lives respectively. He suggests that the most suitable analysis is:— Total carbon, 3.50 min.; combined carbon, 0.50 max.; silicon, 1.80; manganese, 1.20 max.; sulphur, 0.03 max.; and phosphorus, 0.06 per cent. max. He makes an interesting statement that the best results are obtained by blending equal proportions of two different makes of hematite, one high and one low in silicon, together with small additions up to 6 per cent. of steel scrap.

The editorial in The Foundry Trade Journal, Volume 52, February 28, 1935, also draws attention to an interesting statement by Mr. J.

TABLE II.—*Analyses of Cast-Iron Ingot Moulds.*

	Legrand. Per cent.	Shiokawa. Per cent.	Hruska. 1. Per cent.	Hruska. 2. Per cent.	Works A. Per cent.	Saar Works. Per cent.	Witkowitz. Per cent.
T.C. ..	3.25–4.95 as desired.	2.5–3.5	2.5–3.5	2.5–3.0	3.4–3.9	4.0–4.6	3.9
Gr. ..	80 per cent. of the T.C.	70 per cent. of the T.C.	Not given	Not given	70–80	80–88	3.1
Si ..	70 per cent. of the T.C.	1.0–2.0	1.0–1.5	1.0	2.0–3.0	1.9–2.2 not under 1.8	2.2
Mn ..	0.5–0.8	0.5–1.8	0.75–1.20	1.0–1.8	0.5–1.2	0.45	0.59
P ..	max. 0.100	under 0.2	under 0.15	under 0.15	0.08–0.12	under 0.10	0.19
S.. ..	max. 0.050	under 0.06	under 0.06	under 0.06	0.01–0.03	0.06–0.07	
						0.05–0.06 preferably under 0.04 since Cu high	0.039
Cu ..	—	max. 0.2	—	—	—	—	0.11
Cr ..	—	0.05–0.50	—	0.25–0.50	under 0.20	—	—

Legrand.—"Fond. mod." 20 (1926), S. 181/88. Shiokawa.—"Stahl und Eisen," 43 (1923), p. 1140.
Hruska.—"Iron Age," 123 (1929), pp. 539/41.

Léonard, President of the Belgium Foundrymen's Association. Firstly, that different types of moulds fail in different ways, concerning which it is hoped to say something later, and gave as his opinion that, as regards composition, the total carbon should be 3.5 per cent., manganese 0.4 to 0.5 per cent., with 1.7 per cent. of silicon, while further Continental research workers have standardised on 3.75 per cent. carbon and 1.2 per cent. silicon. Mr. Léonard also attaches considerable importance to grain size.

Mr. Blakiston refers to the much longer lives obtained on the Continent, mentioning figures for 4-ton moulds up to 400 casts. Morawa appears to regard 250 casts as a normal life. This matter has naturally had the authors' close attention. They believe, on the one hand, that in Continental practice, where such lives are obtained, moulds are continued to be used far beyond the point at which they would be scrapped in this country on account of the influence on the quality of the surface of the resulting ingot, but, nevertheless, there is good reason to believe that both from the point of view of the quality of the mould and the care taken in its use, Continental practice on the whole is somewhat ahead of the average practice in this country. Some years ago, the authors obtained some moulds from Austria, and the results may be of interest. One batch obtained in 1930 had the following average composition: —Total carbon, 4.0; combined carbon, 0.6; silicon, 0.65; manganese, 1.15; sulphur, 0.014; and phosphorus, 0.23 per cent. These were not of a type on which strictly comparable results with existing types were obtainable, and therefore a further set of six moulds was obtained on the standard 21-in. S.C.T. type in common use in the Templeborough plant. A complete analysis of each of the six moulds is given in Table III, together with the lives obtained and the type of failure. Attention is directed to the comparatively low silicon and the high phosphorus.

The average life of six moulds was 129.6 casts, with a consumption of 16.4 lbs. of mould metal

TABLE III.—*Composition and Life of Austrian Moulds.*

Mould No.	T.C.	C.C.	Si.	S.	P.	Mn.	Ni.	Cr.
1	3.82	0.55	0.86	0.060	0.166	0.75	0.04	0.10
2	3.83	0.60	0.85	0.067	0.162	0.60	0.03	0.08
3	3.77	0.44	0.91	0.060	0.165	0.63	0.04	0.07
4	—	—	0.99	0.070	0.186	0.56	0.02	0.04
5	3.72	0.57	0.91	0.064	0.177	0.58	0.05	0.06
6	3.70	0.57	0.86	0.053	0.180	0.54	0.04	0.07

No.	Life.	Type of Failure.
1	137	Cracked slightly after 132; kept in use until not safe to use further.
2	159	Cracked-up corner of mould.
3	102	Cracked-up corner of mould.
4	138	Cracked-up corner of mould.
5	127	Cracked-up corner of mould after 102 casts; kept in use until not safe to use further.
6	116	Cracked after 72 casts; kept in use until not safe to use further.

per ton of steel made. It was reported that the moulds were particularly tough to break up compared with standard moulds.

The microstructure showed a fairly even distribution of graphite in definitely finer formation than that of a standard mould. At the time of this trial, the average life of domestic standard mould was 95 and the company was advised that the Austrian mould was giving a life of 200 casts on the Continent. It could therefore be calculated that, had the values of the moulds and resulting scrap been similar, the Austrian mould would show an advantage of 2.06d. per ton if used in accordance with English practice and an additional 1.96 per ton if used in accordance with Austrian practice and a total of 200 lives obtained. In point of fact, of course, the Austrian moulds were much more expensive and the value of the resulting scrap was lower. It did, however, establish these two points, namely, that the mould material of these Austrian moulds was superior to domestic, and secondly, that if the figures are accepted, Continental practice is

capable of prolonging the life of the moulds to the extent stated, with the proviso that the quality of the ingot produced towards the end of the life would probably be unacceptable for many of the classes of steel and standard of inspection to which the steelmakers are called upon to work in this country.

Influence of Design

It is not within the scope of this Paper to enter into a detailed statement on this particular subject. Many important Papers have been read and several bibliographies are available to those interested. Quite properly, most of these Papers have had reference to the influence of mould design on the characteristics of the resulting ingot, because, as has before been stated, the saving of one or two per cent. in the yield of satisfactory steel is of far greater importance than extending the mould life. At the same time, a careful study of the way in which moulds fail, indicates that some assistance can be given in design, quite apart from improving the quality of the mould metal.

It is also at once clear that the design of mould should have particular reference to the type of steel being made in that the mould which is most satisfactory and economical in the one case is definitely not so in the other, when one considers the wide range of steels produced, ranging from the perfectly solid alloy-steel ingot with considerable taper (probably corrugated sided) and equipped with feeder head; the larger ingots employed for semi-killed steel for structural purposes; and the mould specially designed for the most economical production of rimming steel. The factors of ratio of length to diameter, taper, shape of sides (*i.e.*, flat, convex, concave or corrugated), corner radius, thickened bottoms, etc., all require to have careful consideration.

Having standardised the type of mould, it is possible to work out more accurately the influence of one or other variable on the economic value. One such set of experiments is given relative to the influence of wall thickness.

Having standardised the 21-in. S.C.T. mould at Templeborough, a series of moulds were made having a wall thickness respectively of $2\frac{1}{2}$ in., 3 in., $3\frac{1}{2}$ in., $3\frac{3}{4}$ in., 4 in. and $4\frac{1}{2}$ in. Six moulds of each thickness were made and used under as nearly similar conditions as possible. The results fell on to a perfectly definite curve and the results are shown in Fig. 1, indicating quite definitely that $3\frac{1}{2}$-in. wall thickness was the most economical for this type of mould. This is quoted merely as an example, and it is readily possible

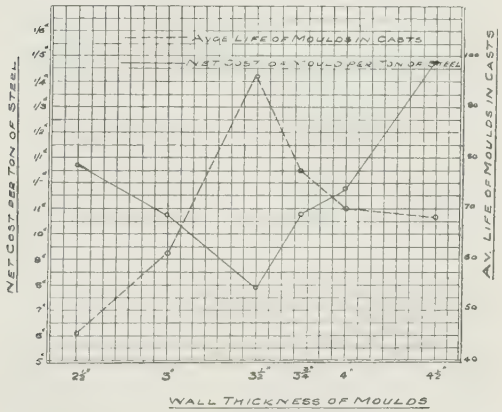


FIG. 1.—INFLUENCE OF WALL THICKNESS ON LIFE OF AND COST OF INGOT MOULDS USING 21-IN. S.C.T. INGOT MOULDS AT TEMPLEBOROUGH.

for any user to ascertain for himself similar data for other types of moulds. It may be added that this has since been checked on other extensive series within the region 3 in., $3\frac{1}{2}$ in. and 4 in. for the mould in question and the desirable thickness of $3\frac{1}{2}$ in. confirmed, and that in these tests such items as the complete analysis of every mould, foundry casting temperature and conditions of use have been most carefully controlled to ensure that the comparison was valid.

The life of the mould will obviously be appreciably affected according as to whether the mould

is used for running direct or casting the ingots through a centre bottom runner. The latter system is kinder to the mould, avoiding risk of cutting by the metal stream due to contact with either mould wall or bottom, but the system adopted must be decided by the effect on the steel produced rather than mould life. Another factor is the use of separate mould bottoms with open-ended moulds which gives a definite improvement in mould life, whether casting uphill or direct.

It is again insisted that the ingot mould is merely a means to an end, and the first important decision to be made in any melting shop is the most suitable shape, size and weight of ingot to give the maximum production of sound steel, together with the most advantageous method of manipulation. It is clearly important to decide in a mass-production plant whether the standard ingot shall be $2\frac{1}{2}$ tons, 3 tons, 4 tons, etc., and this requires to be decided alongside the capacity of the mills before the finer points of mould design can be settled.

Care and Use of Moulds

It was stated, in connection with personal experience in the trial of some German moulds, that the life of the German moulds under specific conditions of use gave a life of 130 casts, compared with 200 casts being obtained in Germany from similar moulds. This at once indicates the importance of the method in which moulds are prepared for use and treated between consecutive casting. The basic principles underlying the care of moulds would seem to fall under two headings; firstly, some method to keep down the temperature to which the moulds are heated in service, and secondly, the treatment or preparation of the mould surface to minimise deterioration by splashing and "wetting." As regards the former, practice varies considerably. In some cases moulds are quenched in water after use, in other cases sprayed with water, in some allowed to stand for specified times on grids, and in some cases supplied with forced draught, while others rely on allowing

Fig. 2.—Corner Crack Defect at Top End.

the moulds to cool normally for not less than a specified time. Shop facilities in many cases preclude the attainment of all one would desire in regard to the resting period between casting, but such experiments as the authors have made by allowing the moulds to cool on special grids indicates a definite advantage from such treatment.

Morawa (*loc. cit.*) quotes detailed experiments in regard to the method of cooling, and finds that air-cooled moulds give the best life, but this entails a large number of moulds and much space for their accommodation. This item must also be bound up closely with the actual composition and structure of the mould metal, in that some types of moulds would suffer much more severely than others if cooled quickly, for example, by immersion in water. It is probably clear, however, that deterioration by a breakdown of the structure of the iron must be minimised if steps are taken to reduce the maximum temperature to which the moulds are raised in service. The spacing of the moulds in setting the casting pit is obviously an important factor in this direction. A practice has recently been developed in Sweden whereby the ingot is pushed upwards in the mould as soon as it is strong enough to be moved, and allowed to rest in the mould after rotating, so that the corners re-engage with the sides of the mould. It is stated that this practice definitely results in an improvement of mould life and incidentally in the resulting product of the ingot.

Mould Facings

Reverting to the second point, particularly if a pure soft hematite mould is being used, it is desirable that the surface shall be protected as far as possible so that the ingot will strip clean, both from the point of view of improving the ingot surface and also to prevent small pieces of mould metal being pulled away when the ingot is stripped. Numerous preparations have been used with this object of preventing steel from " wetting " the surface of the mould. These

include dehydrated tar, usually thinned down somewhat, the old practice of "reeking" by burning creosote oil in the bottom of the mould, rubbing with oily waste, clay wash, aluminium paint, etc. To these are to be added a number of proprietary mould varnishes, which at present are receiving a certain measure of support on the Continent and in this country. It is quite impossible to lay down any fixed rule as to the most desirable method of preparing the inner surface of the mould. This depends essentially on the size and type of ingot being cast. It can be said, however, that in Stocksbridge practice, oiling has been found superior to the other methods tried, and that if used with discretion tar-spraying could be used with advantage in plants such as Workington and Templeborough. A word of warning should be added in regard to the use of tar, either by spraying or swabbing, and that is that great care is necessary to avoid using an excess whereby a pool of tar drains to the bottom of the mould. Under such circumstances, the loss on the resulting ingot far outweighs the advantages. In heavier ingots, particularly where uphill casting is employed, it has not been found necessary to prepare the mould by any of these methods.

The use of a stripping machine gives a definite increase in the life of moulds, apart from the fact of being able to remove ingots from moulds which would otherwise have to be discarded, in that the bumping of moulds to release "stickers" is a contributory cause of moulds failing by cracking.

How Do Moulds Fail?

Considering this matter first from the shop point of view, personal experience which has been very carefully checked up, is that moulds fail mainly through major cracking rather than from breakdown of the mould surface. The authors noted with interest the reference by Mr. Léonard (*loc. cit.*) to this subject, where it was stated that slab moulds failed through

cracks, whilst polygonal moulds finish their useful life through the deterioration of their internal surfaces. It is clearly necessary therefore, to keep in mind the type of mould

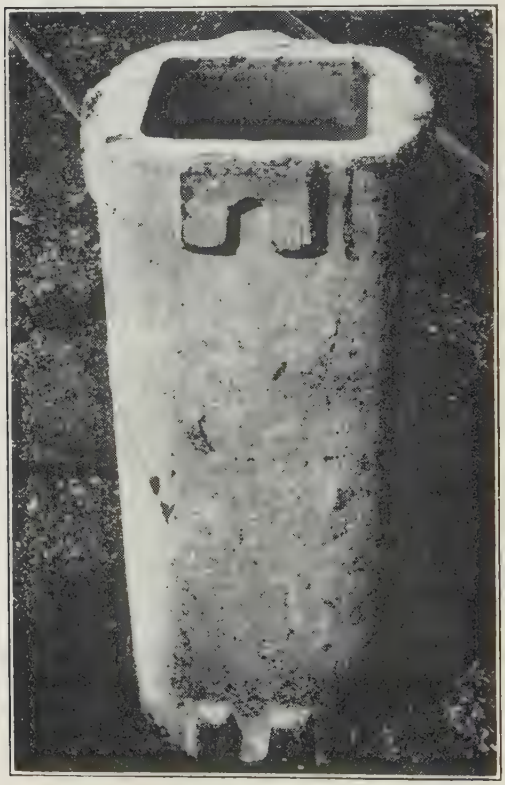


Fig. 3.—Showing the Development of Crack round the Lug.

when speaking of the relative merits of the different factors resulting in the final failure of the mould. Speaking generally, it is clear that for any given type of mould, if a hard, brittle

iron is used, and particularly if it is put into service in a state of stress, it is reasonable to expect that such a mould will crack at an early stage in its life. On the other hand, if the mould be made of very soft iron, and particularly if the graphite is coarse and flakey, then deterioration will be more rapid on the well-established principles of oxide penetration, along the graphite plates.

It seems germane to interpose here that in personal opinion the stresses in the ingot mould as-cast appear to be of a serious order, and the

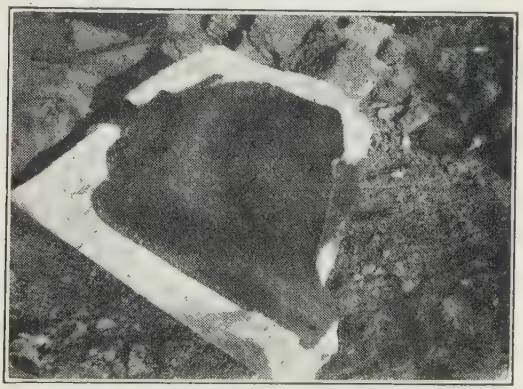


Fig. 4.—Showing a Typical Transverse Crack.

effect has manifested itself in some cases in a rather extraordinary way. Many years ago it was found that, in casting 12-sided tyre ingots of 14-, 17- and 19-in. dia., the first ingot from a new mould was almost invariably cracked vertically in one or more of the corners. If the moulds were annealed at about 800 deg. C. before use, the phenomenon was avoided, and the practice was therefore adopted of always casting an ingot of slag into new moulds before using them for steel. If the stresses in the mould had such an effect on the resulting ingot,

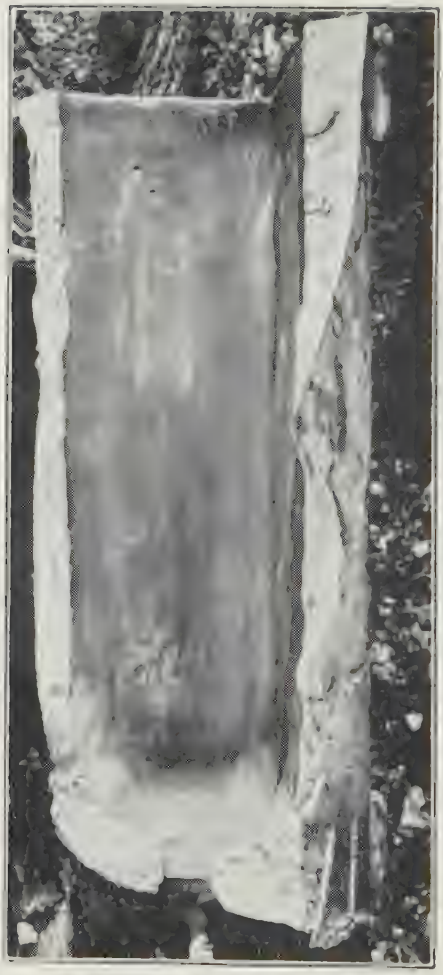


FIG. 6.—INGOT MOULD SCRAPER THROUGH A DEFECTIVE SURFACE

it is clear that the mould requires to be regarded carefully from this point of view if the maximum life is to be obtained. In looking at written returns from the melting shop, it is usual to see the word "cracked" as the reason for discarding, but it is necessary to analyse the meaning of the term in considerable detail. Major cracking often occurs at the top end of the mould where, presumably, it is coolest, and, for example, in the case of 2-ton square moulds, it definitely appears to commence from the outside of the mould. It would appear that, as a result of internal stresses, and more particularly the fact that the iron cannot accommodate itself sufficiently quickly to the increase of temperature from below, cracking takes place. If the mould be fitted with liner bricks at the top or accommodates a feeder head, it may continue to be used for a long time after cracking has started, but it is very often finally thrown out because this crack has developed through the wall, and it is unsafe for further use. The larger moulds appear to fail mainly through cracks on the face, starting about the middle where the mould gets hottest and travelling downwards, while in a number of cases the transverse crack across the face occurs long before the surface has seriously deteriorated. A few illustrations are added typical of some of these defects. Fig. 2 shows a typical corner crack at the top of a mould. Fig. 3 shows a crack round the lug clearly caused by unequal expansion, while Fig. 4 shows a mould which has failed through a transverse crack.

If a mould has not cracked, it continues in use until the surface has deteriorated to the extent of producing bad-surfaced ingots not acceptable to the mill, or ultimately on account of bad surface the ingot cannot be stripped and the mould requires to be broken off. There are, of course, the cases where moulds are scrapped with a very short life, due to bad teeming, when the side of the mould may be scored away, and rough handling in the shop, giving rise to cracking.

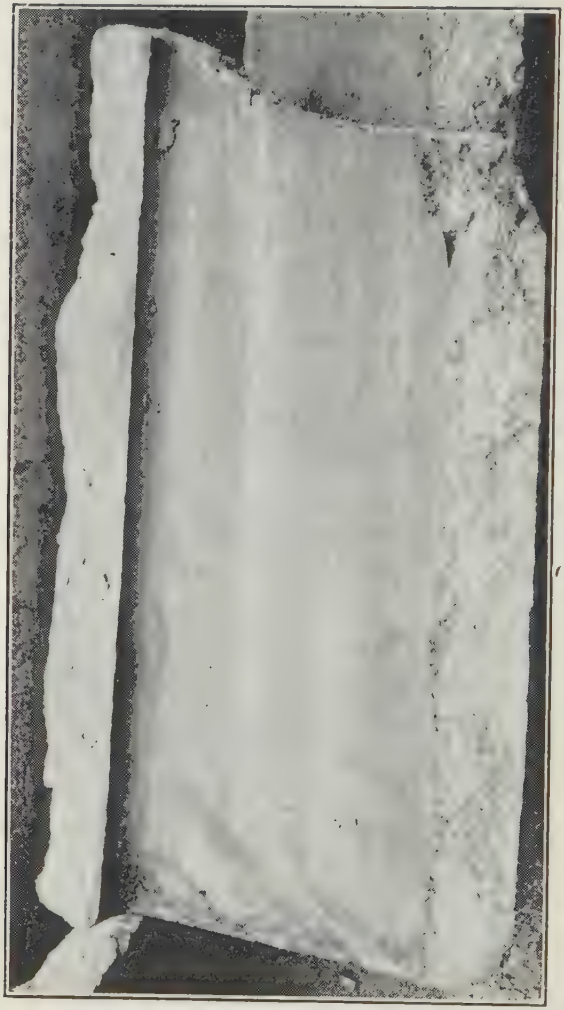


FIG. 6.—THE "SHELLY CORNER" DEFECT.

FIG. 7.—SHOWING THE CRAZED SURFACE, WHICH HAS DEVELOPED AFTER EXTENSIVE USE.

Sometimes the bad surface clearly develops from improper foundry conditions, and results in local deterioration, as shown in Figs. 5 and 6. Otherwise the surface gradually develops a crazed effect, as shown in Figs. 7 and 8, and this ultimately develops into transverse cracks, as shown in Fig. 9. Rapid deterioration round the " plug hole " is a common failing, as shown in Fig. 10. The mould metal is often weak in this position.

Microscopical examination through the section of used moulds is a most entertaining exercise. The authors have nothing new to add to the accepted evidence on this point, but it is certainly curious to know the wide difference in the way in which local fields have deteriorated. In some cases the spaces occupied by the graphite flakes are surrounded by a grey constituent, which is no doubt an oxidation product, and the whole of the carbide has been removed. In other fields it is possible to get perfect pearlite right up to the edge of the oxidised zone.

It has been proved by analysis that there is a slight increase in the sulphur content of the inner surface, possibly occasioned by the rapid interaction of oxide when the moulds are not in use. Careful observation has indicated that, for example, in the case of the 21-in. S.C.T. mould at Templeborough, surface deterioration does not become seriously apparent until after about 70 casts, following which it develops, first gradually and then with increasing rapidity, until the mould is unfit for service. Personal experience, therefore, leads to the following comments under this heading.

Interim Summary of Cracking

A careful survey of the causes of mould failure indicates that the majority of moulds fail through what can be termed " major cracking," and that the principal factor causing major cracking is the inability of the material to accommodate itself to the unequal expansion which takes place when the mould is used. Mould design can assist in obviating premature failure

through certain types of cracks (*e.g.*, corner cracks at the top end) while conditions of use (*e.g.*, ingot spacing in casting) as well as design, will improve moulds as regards transverse-face cracking. An improvement in the quality of the material to enable it better to withstand thermal shock must also be an important line of development. Assuming the mould does not crack, but gradually develops a crazed surface due to the repeated heating and cooling, then clearly the physical characteristics of the mould metal must be looked to primarily to improve the life, together with such a system of use as to limit as far as possible the maximum temperature to which the moulds are heated in service.

Steel Ingot Moulds

It must occur to everyone that, speaking metallurgically, mild steel ought to be far better suited than cast iron for ingot moulds. Steel moulds have, of course, been used from time to time and certain reports are available, stating extraordinary good lives, in some cases up to 700 casts. Steel moulds ought strongly to withstand failure through crazing or cracking, assuming they are made of normal mild steel. Personal experience is very limited, but a trial made some years ago was certainly not satisfactory. The trouble is, of course, that the steel mould distorts badly, and all efforts to reinforce by bends, ribs, etc., have failed to establish the steel mould as a serious competitor. The initial cost would be higher, but if satisfactory lives of the order of 500 to 700 could be obtained, it would undoubtedly become a serious competitor to the iron mould.

The simple explanation appears to be that owing to the greater elasticity of the steel mould, it distorts to such an extent as to make it impossible to cast a regular-shaped ingot and, what is more important, to strip the ingot from the mould after a comparatively short life.

Artificial means of keeping the mould cool have, of course, been tried. Many years ago, the authors experimented with a system of circulating high-pressure air round the outside mould.

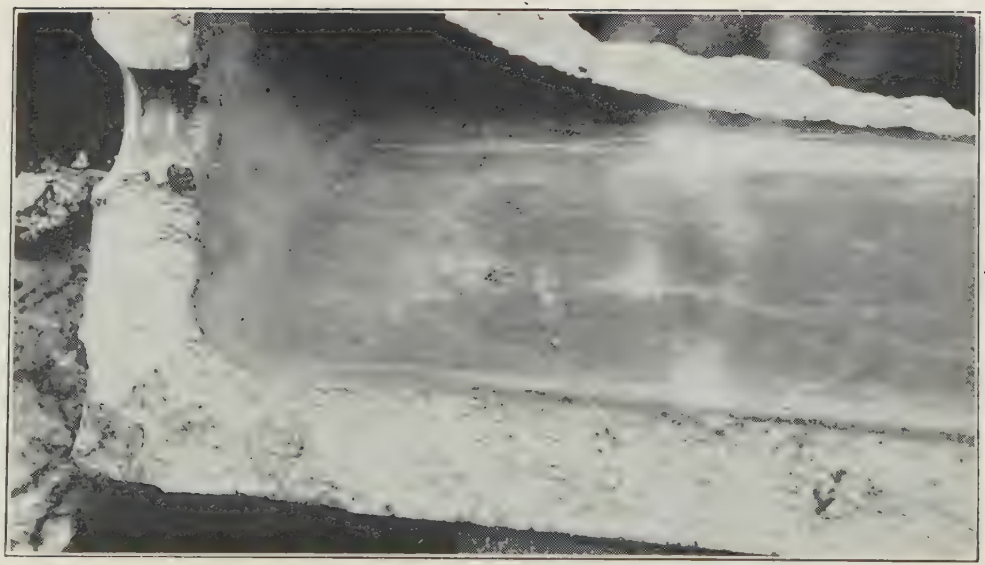


FIG. 8 SHOWS A CRAZED SURFACE DEVELOPING PREMATURELY.

Water-cooled steel moulds have been suggested, but the only system of which we have knowledge, which has achieved a certain amount of success,

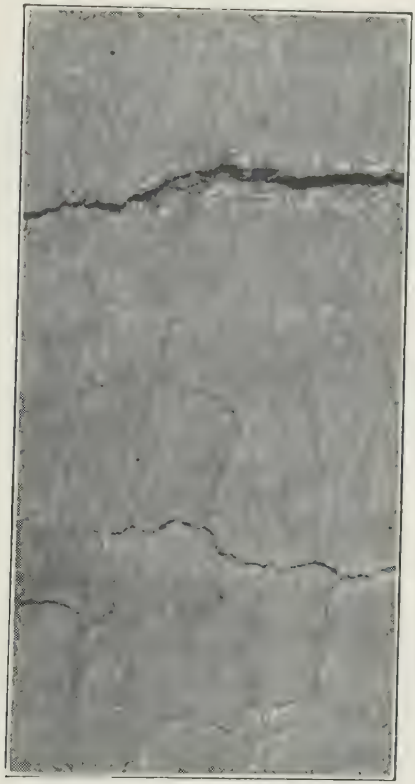


Fig. 9.—Enlarged Photograph of Crazing Developing into Cracks.

is the water-cooled copper mould developed by Rohn* at Hanau. The exact design has been worked out very accurately and the authors have actually seen moulds that have made up to 4,000

* "Zeit. f. Metalkunde," 12/1927

ingots and have examined ingots cast in such moulds.

The cost of the equipment for a production shop would, of course, be extremely high, and one must always bear in mind the risk of damage through mishandling. It is on this account, no

Fig. 10.—Showing Deterioration Round the Centre Runner Hole.

doubt, that the system of using water-cooled copper moulds has not developed to a greater extent.

No attempt has been made in this Paper to give any extensive references to the numerous admirable Papers that have been written on this

subject, but rather an endeavour has been made to state, in simple language some facts concerning experience obtained over a number of years in the plants of the United Steel Companies, Limited. Those interested are, no doubt, well conversant with contemporary work on the subject, and particular reference must be made to the work that has been done by the Heterogeneity of Steel Ingots Committee in conjunction with the Cast Iron Research Association. Further work that is going on now in collaboration with the British Federation of Iron and Steel Manufacturers will probably result in a sound development in the subject of ingot-mould manufacture.

The authors would like to close, however, on the note with which this Paper was opened, namely, that the quality of the steel ingot must be the first consideration, and secondly, that the value of an improved mould to the steelmaker, judged from the cost-per-ton standpoint, must not be over-exaggerated.

In conclusion, the authors record their thanks to the United Steel Companies, Limited, for permission to use the information given in this Paper, which has been collected through the goodwill of the various staffs of the respective works.

DISCUSSION

Ingot Mould Manufacturers Rebuked

Dr. W. H. Hatfield, F.R.S. (Brown-Firth Research Laboratories), who was asked to open the discussion, congratulated the authors on their excellent Paper and expressed the general appreciation of the generosity with which the United Steel Companies, Limited, had enabled them to give the results of a very careful and critical examination of the whole question of ingot moulds in their works. Dr. Swinden and himself, he said, were respectively chairman and vice-chairman of the Committee on the Heterogeneity of Steel Ingots, which was a national committee representing the Federation of Iron and Steel Manufacturers and the Iron and Steel Institute. They were of necessity

following up this subject of ingot moulds in a most thorough and technical manner on behalf of the industry, and he wished to emphasise how generously one of the biggest steel concerns in the country, if not *the* biggest, was making its data available in the Paper. The firms with which Dr. Swinden and himself were associated represented between them nearly 25 per cent. of the monetary value of steelmaking in this country.

Having inquired whether there were present at the meeting any principals of firms engaged in the manufacture of ingot moulds, and having received no response, Dr. Hatfield said he would like the Press, and particularly the technical Press, to state that no ingot-mould manufacturers were present, even though the authors had prepared their Paper at such great pains and with such serious purpose for the benefit of the metallurgical industries. It was reprehensible.

Dr. Hatfield then asked how many of those present at the meeting were concerned with the manufacture of ingot moulds, and he received a response from six; but he disqualified Mr. John Shaw, who was at one time concerned with the manufacture of ingot moulds, but is not directly concerned to-day, so that the total was reduced to five. It was a serious matter, he said, that when so important a Paper was presented on the subject of ingot moulds at the annual conference of the Institute of British Foundrymen in Sheffield, which city was the centre of the special steel trade, there should be only five gentlemen present who were concerned in the manufacture of ingot moulds. It meant that this very definitely practical problem before the steel trade was having to be tackled by the steelmakers and not by the mould makers. He personally appreciated more than he could say the generosity with which the United Steel Companies and the authors of the Paper had come forward with information. He confirmed also that the Federation of Iron and Steel Manufacturers were putting their hands in their pockets in order

to find the money with which to pursue technical developments in this field in a practical way.

Cost of Ingot Mould Castings

Commenting on the statement in the Paper that the ingot-mould costs in the plants of the United Steel Companies, Limited, varied in 1934 from 9d. to 1s. 7d. per ton, according to the type of plant and steel being produced, and that the cost of bottoms varied from 1½d. to 4½d. per ton, he said that those figures were very low. The United Steel Companies were engaged largely in making the cheaper classes of steel, whereas the Brown-Firth Company were engaged largely in making special steels, and had found, as pointed out by the authors, that they could not afford to continue using a mould when its internal surface had become in any sense depreciated, because any external defects on the surface of the ingot might be perpetuated in the final material, and that would be a great disadvantage. In view of the care which had to be exercised in that respect, the ingot-mould costs in the Brown-Firth works were from 5s. to 10s. per ton of ingot metal, and the cost of moulds per ton of finished product was substantially higher than those figures. So that this was a very real economic problem. In order to afford a comparison between the figures given in the Paper and those of the Brown-Firth Company, he said that if the company secured 20 casts from a 12-in. by 14-in. mould, the mould cost was 8s. 8d. per ton of ingot; if they secured 200 casts from the mould, the mould cost was reduced to 11d. per ton of ingot. Assuming a yield of from 55 to 60 per cent. of finished product, one could appreciate that when working on the special steels the cost of ingot moulds became a very serious factor indeed; unless the selling price of the finished products was very high, the mould cost was not the 1 per cent. mentioned by Dr. Swinden, but multiples of 1 per cent.

Discussing the use of big moulds, Dr. Hatfield gave figures relating to a mould, the weight of

ingot produced being 112 tons, the weight of the mould 93 tons, and the cost of the mould £1,600. Such ingots were being made in such moulds regularly and frequently. Assuming that disabilities such as were referred to in the Paper came into operation, and something went wrong with the mould after three ingots were produced, a serious financial loss was sustained. If ten or fifteen ingots were produced, the cost of moulds was still on a plane, as regards cost per unit of steel produced, which called for the most earnest consideration of the Institute and of the mould-makers themselves. He stated publicly that the mould makers were not giving sufficient attention to the subject, they were not helping in a practical way, they were not putting money down for research and they were leaving the steel trade to "carry the baby" all the time. Nevertheless, the latter were able to look after themselves.

Ingots weighing nearly 200 tons were being cast, and it was proposed to cast ingots of much greater weights. What would be the price of a mould to produce an ingot weighing 250 tons? Even these bigger moulds suffered from the disabilities of the smaller moulds, with which the authors had dealt so ably.

Continental Practice

Dr. Hatfield recalled the visit paid by members of the Iron and Steel Institute to Luxembourg last September. They had been entertained magnificently, works were thrown open to them without stint and technical facts were placed before them very freely. In one of the big steelworks there as many as 200 ingots were being produced from one mould; that was in excess of the mould-lives in this country. There were two sides to the question, as the authors had pointed out, but it would hardly be fair to say, without technical support for the statement, that the ingots produced in Luxembourg were worse than ours or that the surfaces were unsatisfactory. But evidence pointed to the fact that the study of ingot moulds on a grand scale, such as Dr.

Swinden and himself, with the help of the Heterogeneity Committee, were engaged in, would result in greatly extending the lives of ingot moulds. That would be the reply to the mould makers, who were so much in the wrong in not being present at the meeting to give due welcome and consideration to the magnificent Paper put forward by Dr. Swinden and Mr. Bolsover. If the Institute were so interested in this matter on the technical side, the Ingot Mould Sub-Committee of the Heterogeneity Committee might be persuaded, as time passed, to lay before the Institute the results of their investigations.

Mr. J. G. Pearce (Director, British Cast Iron Research Association) said the Paper was particularly valuable, coming as it did from two authorities having such wide practical experience of ingot moulds. If in some respects the authors had confirmed what was already fairly well understood, such confirmation, in view of their resources and experience, was doubly valuable, because it all added to the data at our disposal in trying to formulate ideas as to why ingot moulds failed and in what directions we must look for improvement. Mr. Pearce said he had felt glad that the authors had put the question of ingot mould costs per ton of steel into better perspective, until he heard the remarks of Dr. Hatfield; and it was astonishing that there was so great a difference in costs when alloy steels had to be dealt with. For ordinary steels it was of no use less exaggerating the savings that were to be effected by making improvements in the mould, and he was glad that the authors had stressed what he regarded as the best reason for improving moulds, the improvement of the surface of the ingot.

Table I was very important and very useful, and, without wishing to impose on the authors' generosity, Mr. Pearce suggested that it would be useful if one or two of those who were specially concerned with ingot moulds could have access to the sketches to which the authors had referred; he did not suggest that the sketches need be printed with the Paper, but he felt that

it would be extremely useful to associate the design, size and thickness of the ingots with the lives of the moulds in question.

German Moulds

Mr. Pearce was particularly interested in the references made to German moulds* because he had been in some of the large German ingot mould works, and, judging by their compositions and structures, he had never been convinced that their moulds would give longer lives, if used under English conditions, than we in this country obtained from our moulds. The figures given by the authors in relation to the special German moulds, which were definitely good, related to moulds having finer graphite size and a smaller percentage of phosphorus—two very salient points.

The experience of the authors was that large ingot moulds failed by major cracking; but that experience was not universal. In some works it was found that ingot moulds failed in a manner which would be regarded normally as the ultimate end of an ingot mould, *i.e.*, by crazing on the mould face—the formation of the honeycomb or crocodile marking of small cracks which ultimately joined up and enlarged, so that the mould was discarded because of the markings it made on the surface of the ingots produced. Mr. Pearce agreed that we must look to improvements in design and operation for affording greater resistance to the major cracking; and we must look to changes in composition and structure for greater resistance to minor cracking or crazing.

Co-operation by Ingot Mould Makers

At intervals during the past few years he had had occasion to talk to Dr. Hatfield about what Dr. Hatfield regarded as the indifference to mould improvement of the independent ingot mould maker. Without entering into their reasons, Mr. Pearce believed there was a good deal to be said on their side, and the ingot

* See p. 248.

mould makers could make themselves effective technically through the British Cast Iron Research Association. He had met them at intervals and had found them quite prepared to supply the material on which investigation could be made; and it was on that basis that some work was done for the Heterogeneity Committee a few years ago.

Dr. Hatfield asked if Mr. Pearce could be precise and could say what the ingot mould makers had done, because he was giving a false impression.

Mr. Pearce replied that, organised through the Research Association, they had played their part in evolving the process to which the authors and Dr. Hatfield had referred.

Dr. Hatfield:—Be honest about it!

Mr. Pearce said that that, at any rate, could be accounted in their favour.

Technical Requirements

It would be premature continued Mr. Pearce, to say a great deal about that particular process at the moment, except that experience and technical examination alike suggested that an ingot mould metal should have a very high carbon content, but that, in order to enable the metal to resist crazing, the graphite should be in a fine state of sub-division. At present it was virtually impossible, under ordinary green-sand casting conditions, to produce a high total carbon iron with a very fine graphite. The improvement of cast iron during the last 10 or 15 years by reducing graphite size had been accomplished in the main by reducing the total carbon content; with the reduction of total carbon content, the graphite size was improved. At present, if the iron must have a high total carbon content, one had to risk the graphite being coarse, and the Research Association had made some proposals by which an iron having a carbon content of, say, 3.7 or 3.8 or even 4 per cent. could be produced containing graphite as fine as it was possible to produce graphite in cast iron. Under those conditions he believed

the metal was able, by virtue of its carbon content, to withstand the thermal shock imposed by the molten steel, whilst at the same time the fineness of the graphite prevented the entrance, at the working face, of hot gases which led to oxidation, and ultimately to growth and the cracking which he referred to as "crazing."

Higher Phosphorus Suggested

Alternatively, there were various other directions to be explored with regard to composition, one of the most interesting of which was phosphorus. It was not easy to produce an absolutely sound and uniform casting when the phosphorus content was down to hematite value, and that problem had to be explored.

It might conceivably be found that a coarse graphite was ultimately the most desirable form. If that proved to be the case, the B.C.I.R.A. could reverse the process he had mentioned for treating the molten metal, and thus procure an extremely coarse graphite; and if necessary, artificial cavities could be created in the metal. If cavities were helpful, one could produce cavities which did not contain graphite. But there was a limit to that, because a cavity might produce a local hot spot, if a certain limit were exceeded. However, if the cavities could be produced artificially, they might be helpful. Either end could be achieved, and Mr. Pearce welcomed the opportunity of co-operating with Dr. Hatfield's Committee in this direction.

An enormous amount could be done in the direction of ingot mould improvement by effecting improvement in design and in conditions of operation, but it seemed likely that that must be done for each works for its own types of mould and its own particular products. In view of that, there was a good deal to be said for working on what might be called a standard composition, a standard structure, being material which was calculated to give the best results in the ordinary way, leaving it to each works to find out for itself the precise thickness of mould, type of design of mould, lug arrangement and conditions of operation—such as temperature, pouring proximity of moulds to each other, and

so on, which factors, as had been shown, had such a pronounced effect on the life of moulds.

Finally, Mr. Pearce commented again on the value of the data provided by the authors, and expressed the hope that Dr. Hatfield would have no reason to complain during the next year or two of the response on the part of the ingot mould manufacturers.

Mould Preparation and Cost Reduction

Mr. J. H. Cooper was particularly interested in the Paper because during the last fortnight he had had the opportunity of acting as interpreter for a German who was very much interested in ingot moulds. This German friend, having seen the conditions of casting in this industry, and knowing the conditions in Germany, in the Balkans and in other parts of the Continent, considered that not quite sufficient care was taken here in preparing the moulds before casting. The ingot-mould temperatures when casting in this country were higher than those used on the Continent. He was in a position to be an authority on the subject, because his father was the inventor of the steel mould and had placed it before Messrs. Krupps, at Essen, in 1912 or 1913, receiving from that company a considerable sum by way of licence. He contended that if we in this country exercised care in our treatment of moulds, as was done in Germany, and cast in a proper manner, the lives of moulds in this country would be extended very considerably.

Mr. Cooper did not profess to be the possessor of special knowledge, but having had the opportunity of interpreting for a man who knew his business, who had seen the conditions here and was working on these matters on the Continent, it appeared that the fault might not lie entirely with the ingot-mould makers, but that there might be some fault on the part of the steelmakers. If an extra 2d. or 3d. were spent on the preparation of a mould, it was more than 100 per cent. repaid by the extra life of the mould and the better surface of the ingot produced.

Ascertainment of Cost of Castings

Mr. J. Blakiston said it was only by collaboration by people such as the authors, who tabulated the facts concerning the lives of ingot moulds in so precise and ideal a manner, that progress could be made to rectify the production of ingot moulds, which gave such uncertain and irregular service.

Commenting on the authors' reference to the Paper he had read before the Middlesbrough Branch of the Institute recently, Mr. Blakiston said that when he had quoted the cost of the castings per ton of semi-finished steel he had been speaking, of course, from the foundry point of view, and he had based his figures on the approximate cost of two separate iron and steel works—one producing a quarter of a million tons and the other producing one million tons per annum. He had not taken into account any credit from scrap returned, but merely the bare foundry cost to the works concerned. He considered that returned scrap might be regarded more or less as a perquisite to the steel plant, in the same way as they regarded basic slag. The figure of 10s. per ton of semi-finished steel, as given in that Middlesbrough Paper, represented the entire cost of all castings used, from the raising of the coal from the colliery to the rolling of the finished product.

With regard to the lives of ingot moulds on the Continent, he said he had received recently a letter from an Austrian iron-producing firm, who had stated that they were supplying their iron to certain firms of ingot-mould manufacturers, and that the latter were securing an average of from 350 to 400 lives per mould. No other details were given as to the characteristics of the iron; but, of course, much depended on the class of steel produced.

Considerable research work had been carried out in connection with the metallurgical treatment with a view to improving the lives of ingot moulds, but research on the method of moulding and the tabulating of results in that direction

seemed to have been neglected. He was convinced that the biggest factor determining the lives of ingot moulds was the system adopted for the manufacture of the cores and the subsequent method of cooling and easing of the casting.

Elimination of Core Barrel

He had advocated that, if possible, the core barrel should be eliminated, and he had since learned that a Scottish firm had successfully achieved this, the results they were obtaining from their moulds being much superior to those he had seen in English practice.

There was considerable scope for research in this direction; if a graph were made, plotting the sand strength of the cores against the lives of the moulds, he believed one would find a definite relation. One of the Institute's sub-committees had introduced what was to his mind a very good sand-testing apparatus.

In his opinion, when a mould cracked early in its life, the initial crack or plane weakness was inherent in that mould when it left the foundry. It was useless to say that it was cracked as the result of abuse in the steelworks, because the steelworks' manager was concerned more than anyone in prolonging the life of ingot moulds, and must be credited with that intention. It behoved the foundry, therefore, to produce moulds that would stand up to the requirements of the steel manufacturer.

Mr. John Shaw said that the value of the Paper was enhanced by the care which the authors gave to any investigation they undertook. Hence, their data and conclusions should be of great use both to users and makers of ingot moulds. The authors had not attempted to put the onus on anybody, but had given a fair and detailed account of their actual experience.

The figures in Table I were interesting. Without asking for information concerning the abnormal increase in the life of ingot moulds at some works, Mr. Shaw said it would be interesting if the authors could give some more detailed

reason for the 30 per cent. difference between the highest and lowest figure at their plant when using the same type of mould made by the same maker. Was it due to a few moulds cracking soon after they were put into service, thus unduly reducing the average life, or was there some other fact to account for it? Whilst there was a fair amount of proof that composition, within the limits usually found in this class of work, was not the dominating factor, the figures given in part of Table II were fantastic and had little meaning.

Where Continental Moulds Excel

Mr. Shaw was in full accord with the authors' remarks concerning the importance of structure. It was generally accepted that a close structure inside the mould was required to resist breaking down, while the background should be open enough to withstand the sudden expansion occurring when the steel was poured in. It was on this matter that Continental makers had a big pull. The iron from the blast furnace was stacked not only by analysis, but in casts; from this it was easy to estimate the ultimate structure. In this country, however, whilst often the analysis was within the limits given, one found structures from a badly-scattered fracture that would melt hard, to open kishy sows that filled the air with flying graphite as the temperature of the molten metal dropped. Yet with a demand for a maximum of 0.05 sulphur and phosphorus, one was almost compelled to use an open iron if cupola melted.

American Practice

Some time ago he had been asked to pick up what information he could regarding the life of moulds in the States. The experience at several shops varied a good deal, depending on whether the shop was working on tonnage steels or quality steels. John Kruska, who was an acknowledged authority on the subject, had given data confined to square moulds for from 3- to 5-ton ingots. Briefly, the results were as follow (page 233):—

Type of metal.	T.C.	Si.	Mn.	S.	P.	Cr.	Average grade of steel cast in.	Life.
Direct BF. ..	3.80	0.99	1.08	0.035	0.110	—	0.164 per cent. C	69
,, ,, * ..	3.80	0.99	1.08	0.035	0.110	—	0.164 ,, ,,	77
,, ,, ..	4.14	1.31	0.92	0.061	0.106	—	0.12 ,, ,,	62
,, ,, * ..	3.47	1.56	1.23	0.058	0.136	—	0.30 ,, ,,	94
Cupola iron ..	3.66	1.52	1.24	0.051	0.136	—	0.46 ,, ,,	121
,, ,, ..	3.37	1.98	1.18	0.052	0.113	0.78	0.25 per cent. Ni, Cr	119
,, ,, ..	3.27	1.55	0.99	0.079	0.120	0.21	Med. C alloy steel	1[illegible]

Whilst these results did not give a definite lead, there were two points to be noted, and which might help. The two items marked * were held in the ladle for 2½ hrs., and in every case tried these castings had given a longer life than those cast at once. Also, the de-sulphurising process as practised by the Valley Mould Company undoubtedly lengthened the life. There was little doubt that the claim made on the Continent, that mould life averaged 150 heats or over, was correct.

Continental Lives

He had visited quite a number of shops. At Trinec the life was given as from 150 to 200 casts. At the same time, there was little doubt that they used a mould for longer than would be tolerated here, as those who had examined a mould shown at the Liège exhibition, which mould had given 230 casts, could testify. This was confirmed by an investigation carried out at Skoda on a mould after use. From a cross-section of this mould, drillings were taken at intervals of ½ in., commencing at a point ¼ in. from the inside surface. The original analysis was T.C. 3.54, Si 1.43, Mn 1.26, and P 0.104 per cent. At ¼ in. from the inside surface the T.C. had dropped to 1.86 per cent., and it was not until a point 1¼ in. from the inside surface was reached that anything like the normal figure was obtained. The Si and Mn were affected in the same way. Mr. Shaw suggested comparison of these figures with those given on page 147 of the Fourth Report of the Committee on Ingot Moulds.

With regard to Table III, he asked if the authors could say where to obtain with regularity iron of Si 1 per cent. and S 0.03 per cent., which would be necessary to give such an analysis from the cupola. Even the analysis of Table III did not guarantee a long life, as was shown by the results with Kruska's direct-blast-furnace metal; it practically came into line, yet it yielded only 69 casts. Mr. Shaw suggested that these moulds were cast from mixer metal, with its purifying and sulphur-reducing action.

Phosphorus Content and Increased Lives

Discussing the effects of increasing various elements, he said claims had been made for phosphorus up to 0.2 per cent., and there was somewhat wide evidence on this point. Some time ago he had been asked to pay special attention to a certain used mould which had given exceptional life; the only unusual feature discovered was that the phosphorus was up to 0.23 per cent. Further evidence in support of the claim for high phosphorus was furnished by a French Paper, in which reference was made to a mould, cast in error, containing P 0.4 per cent. and which had yielded 214 casts. Phosphorus contents of from 0.15 to 0.20 per cent. were very common.

In Table III the phosphorus contents rose to 0.186 per cent. Whilst it might not be possible to approach this limit, due to re-using, for steel, evidently it was not very harmful to the life of moulds. Mn had also been advocated and had proved beneficial. Groselande had found that by raising the Mn content from 0.6 to 1.75 per cent. the number of casts obtained from one mould had increased from 110 to 175 as an average over two years.

Chromium had also been tried, with a fair amount of success, but much depended on how these additions were made. If they were made in concentrated form, one obtained quite a different structure from that obtained when less drastic means were used.

Treatment in Steelworks

Mr. Ballantine (who represented the Scottish firm referred to by Mr. Blakiston) said that when he examined reports concerning the lives of moulds, he was between the devil and the deep sea. His firm manufactured 6½-ton moulds to a standardised design and supplied them to two different firms, and it was interesting to note that whereas one particular concern obtained something like 150 casts from those 6½-ton moulds, another concern obtained an average of only 50.

Some time ago there had been a discussion as to the effect of low silicon, in conjunction with low manganese, on the life of 20-tonners. He had experienced a very disastrous period with new designs of 20-tonners, and the metallurgists had said that the trouble was due to the silicon being about 1.3 per cent. The manganese never exceeded 0.5 per cent. He was not a metallurgist, but he studied records. Out of 21 moulds made, all 20-tonners, some eight or nine had failed fairly soon. It was reported that the trouble was due to low silicon in conjunction with low manganese. But some 10-tonners were cast in the very same metal, 350 having been made over a period of a year, and there was only one failure. It seemed to him, speaking as a practical foundryman, that the trouble did not arise in the mould foundry itself but in the steelworks.

Machined Tops

Mr. Ballantine asked if the authors had found it advantageous to machine the tops of ingot moulds. He was not aware of the practice in England, but in Scotland the moulds were seldom machined. The steelworks were always looking for a bee in the bonnet, and claimed that moulds ought to be machined at the top. In steelworks one saw moulds from which a piece of dirt had been dug out by means of a pen-knife, and it was said that that was a factor in decreasing the lives of moulds. He had seen billets with as much head on them as there was in the ingot mould itself, and with plenty of dirt. However, it was a delight to listen to this very good discussion on a first-class Paper.

Prof. J. H. Andrew (Professor of Metallurgy, Sheffield University) commented that the Paper dealt largely with the statistical side and contained very interesting data; but one rather missed information which might have been given on the purely metallurgical side. He would be interested to know, for instance, whether the authors had taken depth analyses

from a mould which had been in continuous use for a considerable time, to ascertain whether the chemical analysis varied very considerably from the outside to the inside. He also asked if the carbon varied very considerably after use, and whether the authors could give any idea of the variation of microstructure from the outside to the inside after use. Reference was made in the Paper to distortion, and Prof. Andrew asked if the authors regarded this as purely due to expansion or as being due to growth. When one noted the large inter-crystalline cracks in Fig. 9, one was bound to associate the cracking, generally speaking, with large grain size; and, further, the fact that those cracks rather followed the cracks on the skin of the mould suggested that they were due in the first place to oxide penetration. Could the authors give an idea of the nature of the boundary phase after cracking?

Lastly, Prof. Andrew asked why, as pointed out by Dr. Hatfield, the life of a mould used for casting alloy steels should be very much less than that of a mould used for casting ordinary plain carbon steels. He pointed out that most steels of this character were cast at very similar temperatures—the difference was not 50 deg. Did the alloying elements diffuse into the moulds? Why should alloy steels have a more penetrating effect on the mould than had the ordinary carbon steels?

German Ingot Moulds

Dr. P. Longmuir, M.B.E. (Past-President), congratulated the authors upon their excellent Paper, and reminded the audience that Dr. Swinden's first Paper to the Institute, dealing with pyrometry, and presented at Middlesbrough many years ago, was followed by a second, delivered at the second Manchester convention, on cupola slags, which latter remained a classic to-day.

Referring to German ingot moulds,* he said that undoubtedly they gave a longer life than

* See p. 248.

the English; but that longer life was not necessarily due to the composition of the metal, and, as a rule, the phosphorus content was higher. Although mixer metal was largely used there, and even direct metal, he believed that the majority of German moulds were cast from cupola metal or, alternatively, from metal melted in furnaces of the Brackelsberg type. Our Continental friends were prone to use lacquers; whether or not that was an advantage it was difficult to say, but Dr. Longmuir said that he had some samples, and if the authors were interested he would be glad to forward them for examination.

Armour Plate Moulds

Mr. J. E. Mercer was particularly interested in the authors' reference to the refinement of the graphite. He recalled that twenty years ago a large firm in Sheffield were engaged in the manufacture of ingot moulds to produce large ingots for armour plates and gun ingots. Difficulties arose through high sulphur content, and short lived moulds. Naturally the foundry was blamed. (The hematite was being melted in cupolas.) It was suggested, and carried out, that the hematite be melted in the Siemens open hearth acid furnace, and on occasion as much as 100 tons would be charged into a furnace. The results were very satisfactory so long as good hematite pig was used—the sulphur content being very low and the refinement of the graphite was considerable; thus giving a much better iron and getting a mass of metal that was homogeneous throughout. In casting the metal into the moulds the iron was put into bottom poured ladles and cast through a stopper. This eliminated the usual mushiness so often prevalent at the top of ingot moulds. Some of these ingot moulds for producing steel ingots up to 60 tons each, gave a life of 120 ingots and had a fairly good surface remaining.

AUTHORS' REPLY

Dr. Swinden, replying, expressed appreciation, on behalf of Mr. Bolsover and himself, of

the fact that the discussion had been so interesting and energetic. He emphasised that the Paper was a joint Paper, noting that Mr. Bolsover was the Convener of the Ingot Moulds Sub-Committee, which was responsible for the collection of the data given in the Paper. As one might expect, Dr. Hatfield had contributed and was providing data of very considerable value. One looked to him to continue to contribute such data in the future with the generosity he had shown in the past.

Statement of Lives

Commenting on the ingot mould costs given by Dr. Hatfield, Dr. Swinden said he supposed they were the ingot mould costs per ton of finished steel.

Dr. Hatfield replied that that was not so; his ingot mould costs were related to the ingots alone.

Dr. Swinden said that the ingot mould cost of 1s. 7d. per ton, given in the Paper, was the actual figure attained at the Stockbridge branch of his Company for the last two years, and in point of fact, *something like 75 per cent. of the product there was open hearth alloy steel.* He had not given any figures for electric steel in the smaller moulds.

Taking the point raised by Professor Andrew, he said there was no reason, in his opinion, why the lives of moulds used for alloy steel should be shorter than the lives of those used for casting straight carbon steel. In fact, in his experience the most searching metal was dead soft rimming steel and free cutting steel.

Dr. Swinden reiterated the appeal made by Dr. Hatfield for the support of the ingot mould makers, particularly in view of the fact that there had been established, under the Chairmanship of Mr. R. H. Myers, a member of the Institute, a very active joint Committee of the Iron and Steel Institute and the National Federation, the steel-making members of which had, at very considerable trouble, collected (by means of a questionnaire) and presented, very

full data; it was hoped that that Committee, in collaboration with Mr. Pearce and the users, would tackle this important matter on a national basis.

Reverting to the ingot mould costs, as given in the Paper, he said they were definitely accurate; there was no question that they represented facts. Whilst the figures quoted by Dr. Hatfield was much higher, it represented, presumably, in the case of alloy steel, a smaller tonnage. But even though the costs might be lower and the potential saving might be lower in one case than in another, the importance of the matter was not lessened, because on a tonnage of 10,000 or 12,000 per week the saving of a few pence per ton represented a very big sum in the aggregate. The Paper constituted a deliberate attempt to assess values and to give some indication of how costs could be reduced.

Further Data Promised

The Paper would have been far too bulky if a section on the metallurgical aspects of the problem had been included, and it would have been bad judgment to have included it. But the authors had a complete report on the metallurgical examination of particular moulds which had failed, and the results of the examination of microstructures and so forth, right through a number of moulds that had failed. If it were so desired, that information might be made the subject of another Paper in the future.

Replying to Mr. Pearce's request that he might be given access to the sketches in connection with the moulds dealt with in Table I, Dr. Swinden said that if at any time Mr. Pearce cared to pay him a visit, he could have copies of the sketches.

Discovering Bad Moulds

It was agreed that some moulds did fail by crazing. But, in the authors' experience, where the average life was low, it meant that a number of moulds had failed after 10, 15 or 20 casts, as against an average of, say, 100, and almost invariably the moulds which had failed

prematurely had failed by cracking, and not by sudden and rapid surface deterioration. It sometimes happened that they did get a bad mould! Reference had been made by Mr. Ballantine to the practice of poking about with a penknife; Dr. Swinden said that at his works they made a practice of poking about with a pointed bar, for they had found patches which had been made up with black lead, the result of which was that a mould would fail when it was first used.

One could talk for a long time on the problem as to why moulds cracked, and particularly why a mould cracked at the top corner, which was never in contact with liquid steel. Fig. 2 gave an example of a mould which had cracked from the outside inwards, and that was a very common type of failure.

It was pointed out in the Paper that in the authors' experience the German moulds and others having a somewhat higher phosphorus content than the hematite composition appeared to yield a longer life. The economic aspects, including salvage value, had to be taken into account, but the matter was one upon which attention could with advantage be concentrated in further work.

Care of German Moulds

Commenting on Mr. Cooper's reference to the point that greater care was exercised in the preparation and use of moulds on the Continent than in this country, he said that in the Paper, immediately after Table III, the authors had endeavoured to show that they agreed. They had tried to assess the economic advantage of the German or the English practice, and their experiment—which, incidentally, was duplicated—had shown that there was an advantage of 2.06d. per ton if the particular composition German-type mould referred to were used in accordance with English practice, as compared with the domestic standard mould, and an additional advantage of 1.96d. per ton if the German mould

were used in accordance with the German practice. But it must not be forgotten that if that advantage were secured when using the mould for dead soft Bessemer steel, it must not be thought that the same advantage would accrue if one tried to cast high-carbon steel and maintain a decent surface, because it just would not work.

Dealing with the remarks of Mr. Blakiston, he said he now noted that in the figures given in the Middlesbrough Paper no credit was given for returned scrap. Clearly, in estimating the values quoted in the present Paper, the authors had given credit for scrap at the market prices.

He did not know of any work that was in hand concerning the correlation of the sand strength of the cores with mould lives, but no doubt that problem would be noted for further investigation by the national Committee. The problem of the rate of cooling was already on the programme. Moulds were being made under controlled cooling conditions, and the lives of those moulds in service would be noted.

It was a fact, as mentioned by Mr. Shaw and Mr. Ballantine, that there were quite large variations in the lengths of life of what appeared to be similar types of moulds; indeed, were it not so, it would hardly have been necessary to have written the Paper. The authors had tried to show that such variations were due in some cases to shop practice; if one plotted the figures recorded in the Paper, one found that these variations occurred in waves. However, in a consignment of moulds from the same maker, made of material of similar analysis, and used in the same way so far as shop practice could be controlled, quite large variations occurred as between one mould and another; and that result must be laid at the door of the mould maker.

Composition and Mould Life

The author agreed entirely that analysis was not a governing factor; and he drew attention to the statement, in the section of the Paper headed "Influence of Mould Metal on Mould

Life," that in their experience, which they believed was in full accord with that of many other observers, the composition could vary within fairly wide limits without any consistent effect on the mould life.

Dealing with Mr. Shaw's request for more data concerning metallurgical examination; he said that decarburisation did occur on the surface and differences of composition did develop a considerable distance back into the mould, with some very weird structures in the intermediate zone, due, no doubt, to penetration of gases.

The moulds referred to in Table III were Werfen moulds; they contained fairly high phosphorus.

A fairly extensive trial now being conducted on moulds made of a material with high manganese content suggested that manganese was beneficial, as Mr. Shaw had mentioned. But the authors did not agree that chromium additions were beneficial; they had obtained certain results on small-scale experiments, but those results were not substantiated in larger-scale experiments, so that they had discontinued the use of chromium.

It was refreshing to hear Mr. Ballantine's remarks, but it would be unwise to attribute the whole of the variations experienced in regard to the behaviour of moulds to bad steelmaking practice. That was not the whole story!

Machined Moulds

As to the practice of machining the top of the mould, Dr. Swinden asked if Mr. Ballantine had meant the top of the mould as cast (which was the bottom of the mould as used) or the top of the mould as used.

Mr. Ballantine said he was referring to machining the top of the mould as cast.

Dr. Swinden replied that it was common practice to machine the bottom of the mould at one of his company's plants, but that was done for a special purpose, because an open-ended mould was used, with a bottom plate

having a recessed dish, and it was very important to secure an accurate fit. That practice had led to a very interesting result. The moulds were machined on the bottom in order to register exactly with the bottom plate. But the first ten or twelve moulds used in that way had cracked almost immediately up the side, the obvious reason being that there was no room for the mould itself to expand. When sufficient room was left for expansion, by machining oval holes, the trouble had disappeared. But that was the steelmaker's fault!

Dealing again with the reference to poking about with a pen-knife, he said that when using a mould for uphill casting with a tapered hole in the bottom, often there was soft porous metal around the hole. It was the practice to test that with a sharp bar, because the steel would quickly bite in and pull away a lump, and after two or three heats the mould would be useless. It was important that the mould should be sound in that position.

One did find variations of analysis in a mould, as would be anticipated, and decarburisation on the surface, as well as penetration along the graphite plates.

Distortion

With regard to distortion, Fig. 9 was included in the Paper to show that expansion and contraction and a gradual crazing of the surface occurred, leading ultimately to a type of cracking. But he emphasised that when he had referred to moulds failing prematurely by cracking he did not mean the sort of cracking illustrated in Fig. 9; he had meant cracking which extended right up to the corner and which had no relation to the deterioration of the inside surface.

He and his colleagues would welcome any opportunity of examining further samples of German mould lacquers, which Dr. Longmuir had promised to make available; the more information they could get the more likely would they be able to help themselves and the mould-makers.

As to the suggestion that a higher phosphorus content was not of advantage, Dr. Swinden said he would not go so far as to agree from the point of view purely of mould life; but it was a matter of economics, involving the mould life and salvage value.

Mr. Mercer's interesting remarks confirmed all that Mr. Pearce had said on the importance of treating the mould metal to ensure that the graphite was in the most advantageous form in the resulting mould.

Mr. V. C. Faulkner (Past-President) proposed a very sincere vote of thanks to the authors for having placed such valuable data at the disposal of the Institute and the industry. He imagined that the Paper was one of the most important ever presented at any conference.

The proposal was seconded by the President, and was carried with enthusiasm.

Written Communication

Messrs. Eisenwerk Sulzau-Werfen (R. & E. Weinberger), Vienna, wrote:—

In the production of ingot moulds for steelmaking, the important factors are not merely the conditions considered necessary to produce first-class grey-iron castings, but particularly the conditions of use of the moulds, the latter having the major effect on their life.

The influence of these conditions varies in every steelworks. Hence, comparison of the service given by moulds cannot be made simply by recording the lives obtained. To obtain useful comparative data, the lives of moulds of different origin in the same steelworks must be recorded.

The factors which are of importance as regards the life of ingot moulds are as follow:—(1) The selection of the raw materials for the manufacture of ingot moulds; (2) the method of making the foundry moulds in which the ingot moulds are made; (3) the type of furnace in which the metal is melted; (4) the quality of steel which is cast in the ingot moulds; (5) the manner in which this steel is poured into the moulds; (6) the treatment of the inner surface of the mould

in the steelworks; (7) stripping time; (8) how the moulds are cooled afterwards; (9) bottom plates; (10) the requirements regarding surface of the steel ingot, and (11) the design of the moulds.

The following notes refer particularly to moulds for ingots of 4 tons weight. Points 1, 2 and 3 are discussed in detail, whereas the others are referred to more briefly, as the mould founder has no control over them, although he must consider them.

(1) The most important properties, which the ingot mould metal must have, are highest uniformity of structure, freedom from internal stresses and capacity of resistance to repeated thermal shock. Generally, hematite is regarded as the best raw material owing to its purity, as this ought to give the best guarantee of freedom from stresses and resistance to repeated heating and cooling. This is the case with certain exceptions. The experience of mould founders is that every hematite pig-iron is not equally suitable; although some hematites show good results, others are poorer. This might be due to the physical properties imparted to the pig-iron by the ore.

Very good results are obtained with charcoal pig-irons owing to their freedom from internal stresses and resistance to thermal shock.

The following notes refer to ingot moulds, made chiefly from charcoal pig-iron, as made at our works, "Konkordiahütte," Werfen, Salzburg, Austria. Tests were made with another charcoal pig-iron of a very similar analysis, which gave far poorer results. It seems, therefore, that Werfen charcoal pig-iron is particularly suitable for the manufacture of ingot moulds. We explain this by special properties of the ores, which are very poor and require much fuel for the smelting process. Hence, the iron contains a high percentage of carbon, between 4 and 4.7 per cent.

We consider that the chemical composition of moulds for four ton ingots should be as follows: —Total carbon, 3.90 to 4.10; silicon, 0.80 to 1.00;

manganese, 0.60 to 0.90; phosphorus, 0.15 to 0.20 per cent.; and sulphur, as low as possible. When making moulds of cupola melted iron, we mix our iron with English West Coast hematite and our own runners, risers and wasters to obtain the desired silicon content.

(2) All ingot moulds were cast with the foundry moulds standing upright and the molten metal entering from the bottom.

(3) The moulds were cast from three different furnaces: small cupola, larger cupola and direct from the blast furnace. The records of a steelworks, which extended over several years, included 130,000 casts, *i.e.*, 7,000 casts in moulds made from the small cupola, 39,000 casts in moulds from the large cupola and 84,000 direct from the blast furnace. These showed that the lives of moulds made from the small cupola were on the average 2 per cent. lower than those from the large cupola, the latter being 20 per cent. lower than those direct from the blast furnace. In spite of these records, we may say that we had over 500 lives not only from the blast-furnace moulds, but also from cupola moulds. The records of three steelworks showed:—

Works A.—Average = 338.5 lives (33,193 casts).
Works B.—Average = 241 lives (56,182 casts).
Works C.—Average = 210 lives (129,985 casts).

All moulds which are made with our charcoal pig-iron show evenly-distributed graphite and fine-grained structure.

(6) The protection of the inner surface of the moulds has had a beneficial effect on mould life and has increased it at one works as much as 50 per cent.

(7) Stripping time influences mould life, inasmuch as when ingots are left too long in the moulds, the temperature of the mould not only rises but also fluctuates more considerably.

(8) The cooling of the moulds after removal of the ingots has a very great influence on mould life. The best method is to cool the moulds on

grids, provided that the moulds are not too close together and that air can pass between

(9) From the records of one works, it appears that moulds which were always placed at the outer edges of the bottom plate had 20 per cent. greater life than those which were placed in the centre of the bottom plate.

AUTHOR'S WRITTEN REPLY

Since the reading of the Paper, the authors have had very interesting correspondence with the proprietors of Eisenwerk Sulzau-Werfen (Messrs. R. & E. Weinberger), of Vienna, and this written contribution to the discussion is deeply appreciated. In the first place, the authors tender their sincere apologies and regrets that in their Paper as originally published, the moulds which were reported upon and which had been supplied by this company are referred to as German moulds. The company have properly pointed out to us that these should have been referred to as Austrian moulds.

The analyses of the moulds used and reported upon by us, agree reasonably well with that stated in this contribution except that we found the manganese to be somewhat lower than Messrs. Weinberger consider to be the best. The interesting point is made however and supported by fact in this contribution that the source of the iron and the method of manufacture are of first importance.

We think that no one will disagree with the statement that all the items numbered 4 to 11, in the useful summary of factors which influence the life of the mould are in fact of importance and it is interesting to note that particular attention is paid to:—(*a*) The protection of the inner surface of the mould; (*b*) the stripping time; (*c*) the cooling between casts, and (*d*) the manner in which the moulds are assembled during casting.

The latter three factors all bear on the essential point of the temperature range to which the moulds are subjected in service.

STRICKLE MOULDING OF LARGE CASTINGS

By H. Fabre and H. Dubois

Presented on behalf of the Association Technique de Fonderie

[French Exchange Paper]

Introductory

The authors desire to express their thanks to the Institute of British Foundrymen for the honour it has done them in inviting them to contribute a Paper, and apologise for presenting a subject which has already been dealt with so often, a subject, however, which has the particular property of never being exhausted. Apart from the risks which attract every man of action, loam moulding leaves a great deal to the initiative of the individual. Every problem involved therein carries a certain number of solutions, all of which arise out of a series of laws derived from experience. It is this accumulation of practical data which the authors propose to present and the interest shown will be an ample reward.

Definitions and General Applications

It is not presumed to teach the meaning of strickle moulding, but rather to present a general idea of its numerous applications. There are cases, such as that of complicated castings, where the strickling of certain portions of the mould is imperative owing to reasons to be disclosed later. Alongside these portions are placed such parts of the mould as constitute the form of the casting incapable of being strickled, giving a happy combination of both strickle and pattern moulding.

In loam moulding and where several castings of the same kind are required, this method of moulding permits of re-using the brickwork, whilst pattern moulding would, in the case of

each casting, have necessitated the complete demolition of the mould before each fresh moulding operation. Strickle moulding, from whatever standpoint it may be viewed, affords the great advantage of considerably reducing patternmaking costs, this advantage being emphasised with the reduction of the number of castings to be made.

The chief disadvantage of strickle moulding is that it requires specially skilled men and careful work, particularly in respect to initial preparation, which is a more exacting and precise operation than in pattern moulding. During the actual moulding the operator has frequently to check various data in order to avoid any distortion of the mould, and so to obviate the errors in calculation to which such distortion would give rise when assembling the mould.

In certain cases this method of moulding necessitates the provision of special tackle, but the total cost incurred in patternmaking for this purpose is invariably less than the cost of a full pattern. Finally, in the majority of cases strickle moulding takes longer than pattern moulding.

The examples to be given have been selected to illustrate in some measure the principal classes of work to which strickle moulding may be applied. This Paper being addressed to experienced foundrymen, it is proposed to outline the chief characteristics of each type of job without dwelling upon the details of manufacture with which every foundryman should be familiar.

When Should this Method be Used?

Its application is determined by economic considerations connected with patternmaking or, more rarely, with moulding. It should be adopted in nearly all cases where large plain castings of circular sections or castings in which the main portion is a circular solid are concerned. Where loam is selected as material, it will be advantageous when strickling to obtain a set of castings, so that the provision of special tackle is made worth while. But in

this case, just as in every other, there is no absolute rule; only the profound study of all the data connected with the problem can, when all is said and done, determine the course to be adopted.

Materials

Strickle moulding may be effected either in sand or in loam. The two crafts are, as is well known, quite different. For instance, in the case of sand, there is only one strickle board, in two parts, the equipment used is normal, and the operations are consecutive. As regards loam moulding, however, two different boards are necessary, the two portions of the mould are separated, the equipment is a special one, and the operations can be carried out simultaneously.

Patternmaking

The patternmaking equipment is very simple. As regards sand moulding, it comprises:—(*a*) The "matrix board," serving to obtain the false pattern in sand which permits the ramming of the top portion, and (*b*) the "claw" for hollowing out the lateral and lower shapes of the casting.

In loam moulding, the two portions of the mould being formed independently of each other, two distinct boards have to be provided: one for the upper portion, the other for the body and the bottom portion.

More details of the question of patternmaking will be given in each of the special cases to be considered.

Equipment

The tackle should be of sound construction and be maintained in good condition. It comprises the ordinary moulding tools (circular and vertical, circular and horizontal, rectilineal or curvilineal) and special moulding tools (loam-moulders' horse, eccentric spindle, double sockets, profiling and balanced spindles, threaded shaft, flat strickling). It is not proposed to enter into a detailed description of each of these tools here, but their application will be described in the following sections.

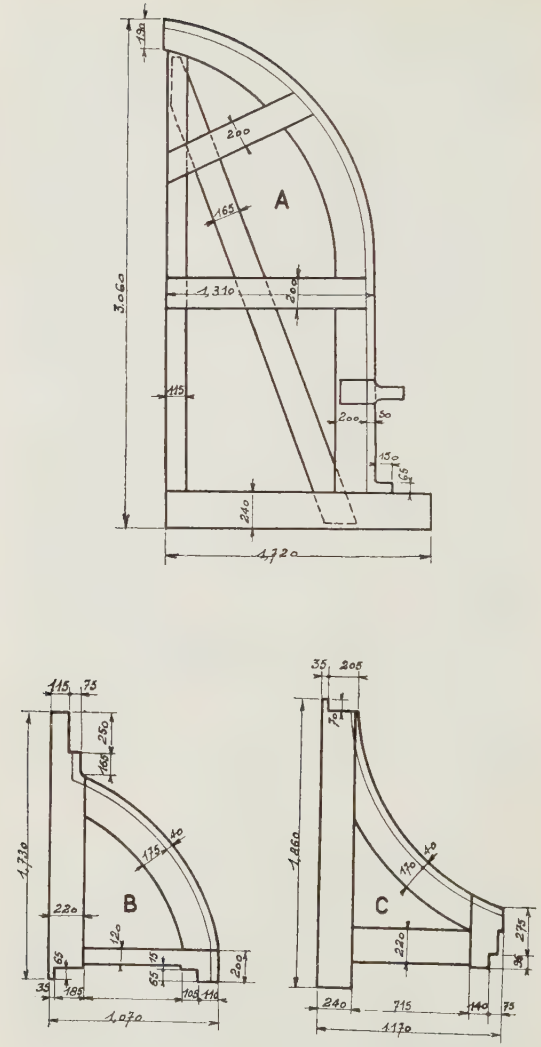
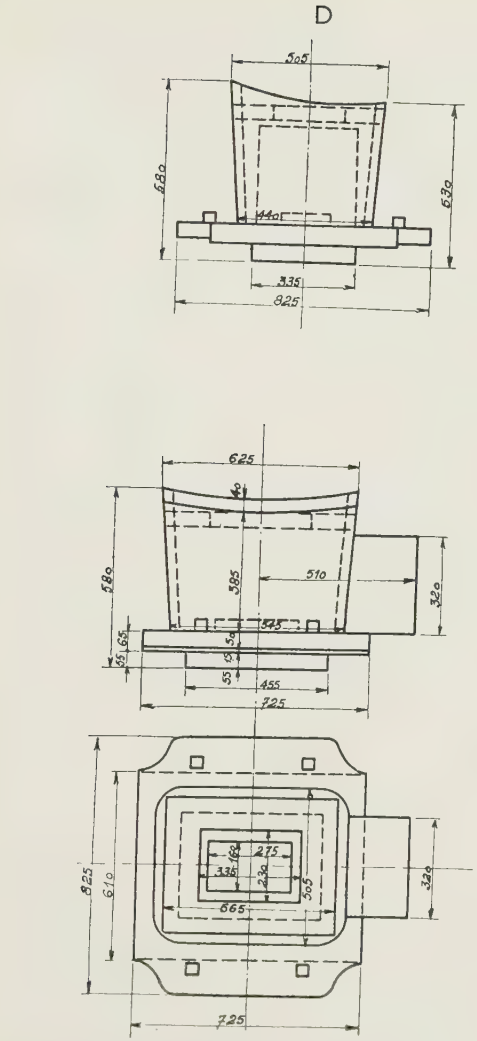


FIG. 1.—TACKLE REQUIRED FOR



Moulding a Blackpot.

Plain Castings of Circular Section ("Blackpot," weight 12 tons)

Vertical Strickle Moulding.—This is a plain vat, but one of large dimensions (height 3.05 m., external dia. 2.81 m.).

Selection of Material.—In selecting the material to be employed, the management is guided by considerations of production costs and facility of execution. In the case of sand moulding one must first consider the use of a large number of moulding boxes of large dimensions, which are, therefore, heavy, cumbersome and very costly. For a casting of this size, the loam mould is more stable than the sand mould, so that its disintegration is less to be feared. The strength of the mould being very great, it is possible to walk in it. This greatly facilitates the operations of assembling or repairing the moulds. If any differences in their thickness are found when assembling, it is very easy to scrape away or to add loam to the sides as required, so that success is more certain owing to the greater stability of the mould. A further and more important advantage is the possibility of re-using nearly the whole of the brickwork in cases where several castings are to be made. Loam moulding should therefore be used.

Patternmaking.—The making of the pattern is very simple. The board A, Fig. 1, serves to strickle the body of the casting. The bottom of the core is strickled, upside down, with the board C and comes to rest on a false portion of the same shape obtained by means of the board B; the top outside rib is represented by the part D, the flange of which is removable on the outside.

Tackle.—The strickling tools do not differ from those used in sand moulding. They comprise a spindle and a socket. The equipment should include a circular plate A upon which the bottom of the mould (Fig. 2) is built up. This plate must rest firmly on the anchorage. The covering plate B carries four lifting lugs on the outside and six lugs inside to enable the core to be fixed. Plates C, D, E are core plates; plate C

carries six countersunk eyes corresponding to the six internal lugs of the covering plate. The latter should not hinder the withdrawal of the casting after pouring. They should leave a sufficiently large margin to permit of their being surrounded by a packing of straw, coke breeze and loam brick. Thus, opposite the grid there is obtained a portion of the mould which will not be too hard: this is very important. Fig. 3

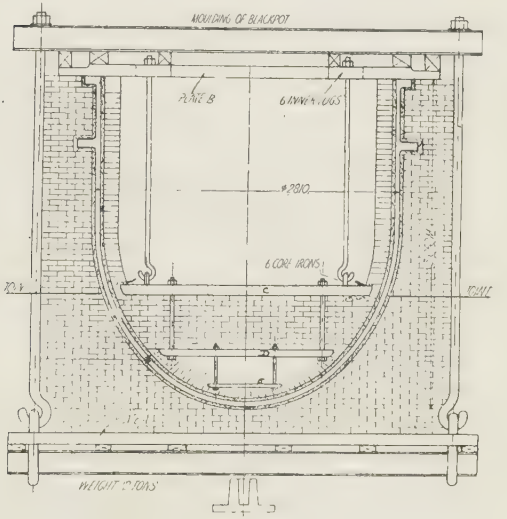


FIG. 2.—SECTION THROUGH A MOULD FOR BLACKPOT.

illustrates the precautions to be taken for this purpose.

Moulding Details—(*a*) *Building the Body.*—The bottom of the pit must be very hard, so as to withstand the pressures imposed on the bed plate during the casting. The building up of the body is effected in two operations, because the bottom cannot be dried *in situ* and has to remain about 24 hrs. in the stove. Immediately the bottom is dry, the brickwork is continued up

to the joint by means of the strickle board, being subsequently dried from the outside by a coke fire.

When the bricks are dry, the hard loam is rammed flat and the mould roughed-out. Finishing is done by ramming the soft loam and strickling, after which the final drying is effected by

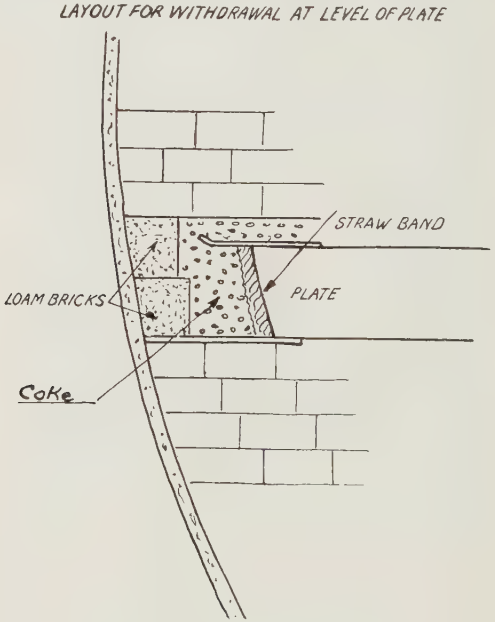


FIG. 3.—MEANS ADOPTED FOR EASY REMOVAL OF CORE.

portable coke fires. All roughnesses in the mould are removed with a scraper, while finishing consists in rubbing the walls of the mould with a damp rag, before subjecting it to blackwashing and a final drying operation.

In building up the bricks every precaution should be taken to ensure the rapid escape of the gases during casting. For this purpose, the

brick joints are packed with fine coke breeze. A channel, lined with slightly coarser coke breeze is formed round the brick course. At the four corners of the vent are placed large pipes running to the foundry floor, their function being to facilitate the escape (always under pressure) of all the gases from the bottom part.

(*b*) *Coremaking.*—The core, like the cope, is built in two operations. The bottom of the core is strickled with the board C (Fig. 4) and stove-dried for 24 hrs. During this time a false core or "cake" is strickled, with the board B, on a plate provided with lugs and also stove-dried. After drying, the bottom of the core is turned up

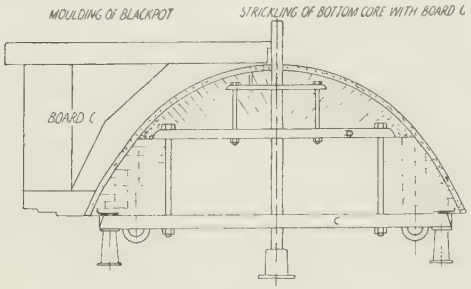


FIG. 4.—CORE FOR BLACKPOT.

into the false core (Fig. 5), the brick course being then completed by means of the board E. The loam is rammed and the mould finished in the same way as for the body, after which the top plate and the bottom of the core are bolted together so as to obtain a rigid whole, which is then stove-dried.

Gates and Risers.—Experience has shown that for this casting, casting should take about 120 sec. The amount of metal to be run in per sec. is therefore 100 kg. It is assumed that the normal speed at which the metal flows into the gates to be 2 metres per sec. Thus:

$$\text{Section of down-gate} : \frac{100}{20 \times 7.2} = 0.76 \text{ dm.}^2$$

the diameter of the gate being therefore = 0.94 dm., *i.e.*, practically 100 mm.

In calculating the dimensions of the risers, the amount of air to be expelled during the 120 sec. must be ascertained. The volume of the mould is:

$$\frac{12{,}000}{7.2} = 1{,}666 \text{ dm.}^3$$

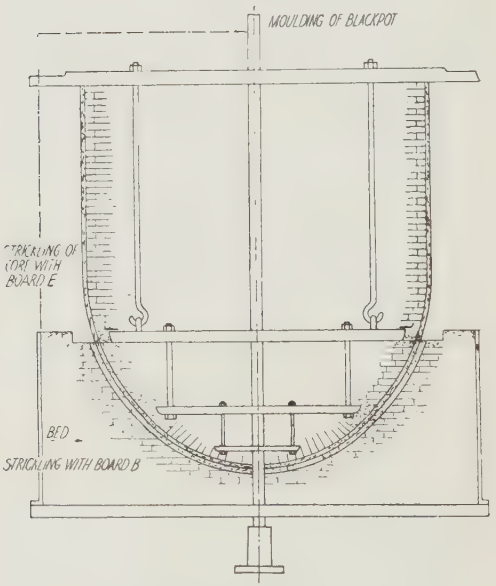


FIG. 5.—ASSEMBLED CORE FOR BLACKPOT.

but taking into consideration the gases formed while pouring, it is judged to be necessary to multiply this figure by a coefficient of 1.5. The amount to be expelled per sec. is therefore:

$$\frac{1{,}666}{120} \times 1.5 = 20.85 \text{ dm.}^3 \text{ of air and gas.}$$

In order to avoid any trouble, these gases should not, in our personal opinion, escape at a

speed of more than 0.20 m. per sec. Thus:

$$\text{Total section of risers} = \frac{20.85}{2} = 10.42 \text{ dm.}$$

These observations as to the calculations for

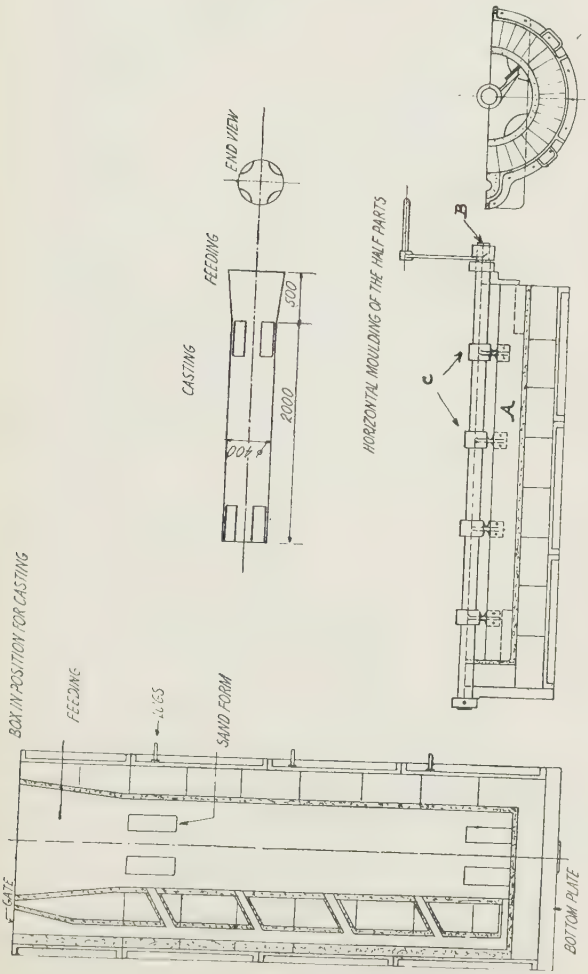


FIG. 6.—EXAMPLE OF HORIZONTAL STRICKLING.

the gates and risers apply to all the castings hereinafter mentioned.

Assembling

Before assembling, it is necessary to check

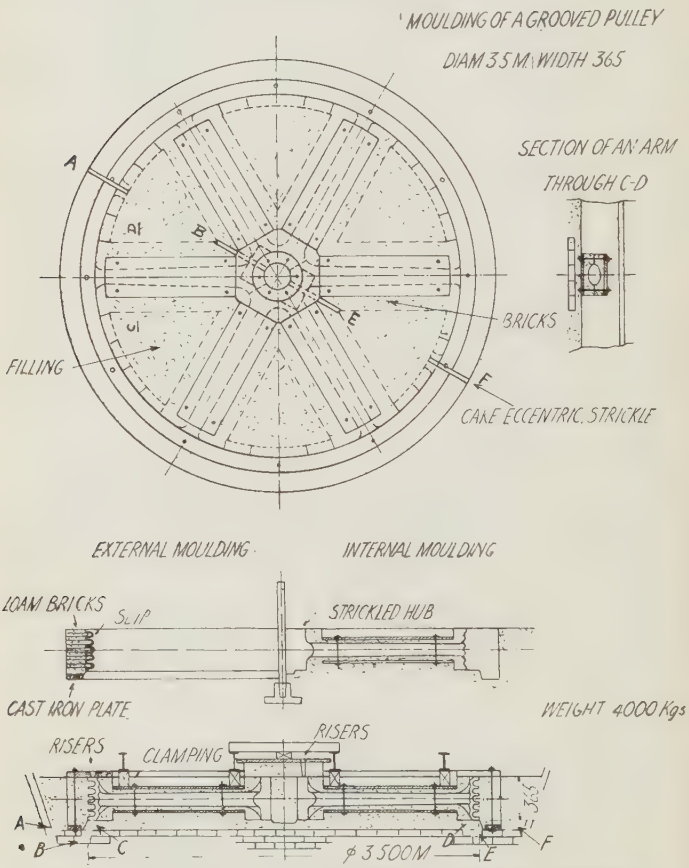


FIG. 7.—METHOD OF MOULDING A GROOVED PULLEY.

carefully the height of the mould as a subsidence of the brick courses is to be reckoned with. Sand is rammed between the outside of the brickwork

and the wall of the pit so as to counterbalance the lateral pressures set up at the time of pouring. This operation should be very carefully carried out, and wherever large castings are concerned all the pressures are to be calculated so as to avoid any error at the time of pouring. The core is then lowered and the top plate and the anchorage are bolted together, as indicated in Fig. 2.

Horizontal Strickle Moulding (Rolling-Mill Roll, weight 2,300 kg.)

The horizontal strickle board is used for strickling in the horizontal position castings which are then poured vertically. In this method of strickling (Fig. 6) the socket is dispensed with. One end of the spindle B carries a square nut which enables a handle to be fitted. For the present casting, four clamps C are fixed to the spindle so as to give to the strickle board the necessary rigidity. As shown in Fig. 6, the moulding boxes (two half-parts) are of a special type and carry on their two small ends, bearings bored to the diameter of the spindle, while their axes corresponds to the mould joint.

The inner walls of the half-parts are bricked up. The loam is then rammed over this brickwork, while strickling is effected as shown in the drawing. The two half-moulds are stove-dried, then assembled and again stove-dried. The two portions are fastened by bolts, of square section, after which the mould is placed in position for casting.

Eccentric Strickle Moulding (Grooved Flywheel in two half-parts, weight 4,000 kg.)

The flywheel shown in Fig. 7 is made by eccentric moulding and is cut by cakes A, B, E, F.

Patternmaking.—The equipment includes:- (*a*) A board for strickling the bottom portion *a*, *b*, *c*, *d*, *e*, *f*; (*b*) a board for strickling the outside of the grooves; (*c*) a board for strickling the inside of the grooves; (*d*) a board for strickling the hub; (*e*) a loam-cake box for making the

loam bricks which are to rough-out the grooves, and (*f*) a pattern for the half-spokes and various other parts.

Moulding Tackle.—The moulding being done in a pit, an annular plate is necessary to brick up the joint, a similar plate to cover the rim and a plate to cover the hub; also plates provided with lugs upon which the half-spokes are to be moulded and then assembled (see section CD).

Moulding.—A thick course of coke breeze is prepared, in order to facilitate the escape of the gases at the time of pouring, while the bottom of the mould *a*, *b*, *c*, *d*, *e*, *f* is strickled; the joint at *a*, *b* represents the seating of the cope plate. The bottom is bricked up at *a*, *b* and *e*, *f* below the hub and at the seatings for the spokes.

When the bottom is dry the positions of the spokes are marked, the spokes themselves having been made separately, in half-sections, on plates provided with lugs, and then assembled. The spokes are then placed flush with the supporting sand, which is rammed under the plate. After laying the spokes, the building up of the inner part of the wheel is begun, this pattern being strickled in loam. The same operation is effected in respect of the hub. Special attention should be paid to the joining of the spokes with the rim and the hub. The covering plates of rim and hub are struck up separately.

Strickling the Body.—The body is strickled on the plate *a*, *b*, *e*, *f*, this operation being effected separately. The body is built up by means of loam bricks designed to rough-out the required grooves and placed in position with the aid of the strickle board. After drying, the body is finished by adding soft loam and strickling in the usual way. This method of making flywheels is very economical from the standpoint of patternmaking and moulding.

Rectilineal or Curvilineal Strickling (Moulding of a Pipe-Bend, weight 1,000 kg.)

Patternmaking.—In making the mould (Fig. 8) the patternmaker prepares:—(*a*) A templet A, the surface of which imparts the

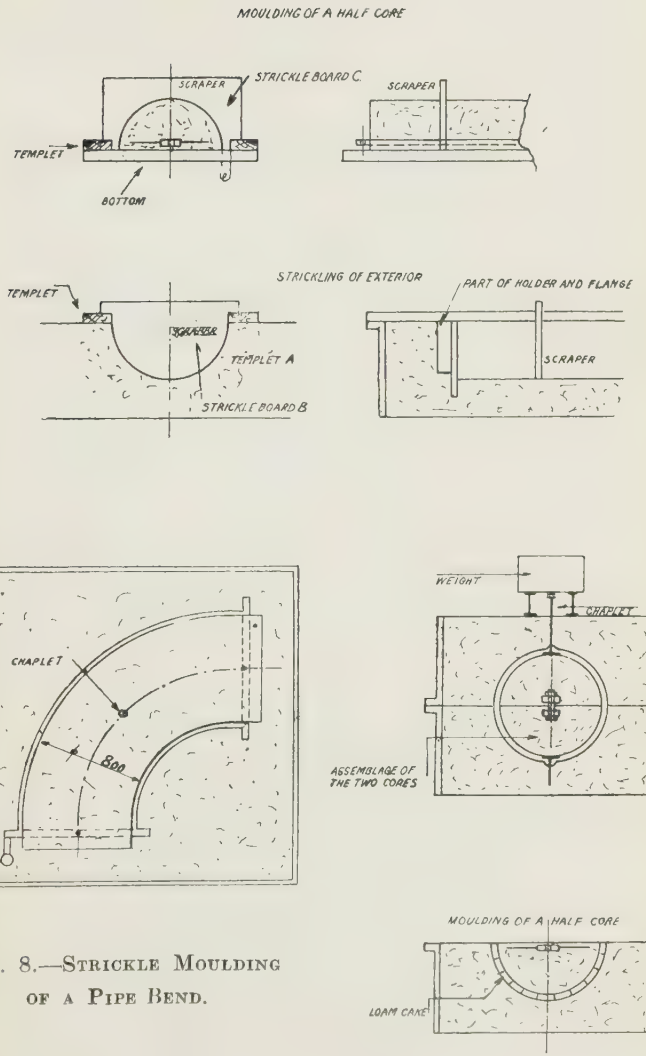


FIG. 8.—STRICKLE MOULDING OF A PIPE BEND.

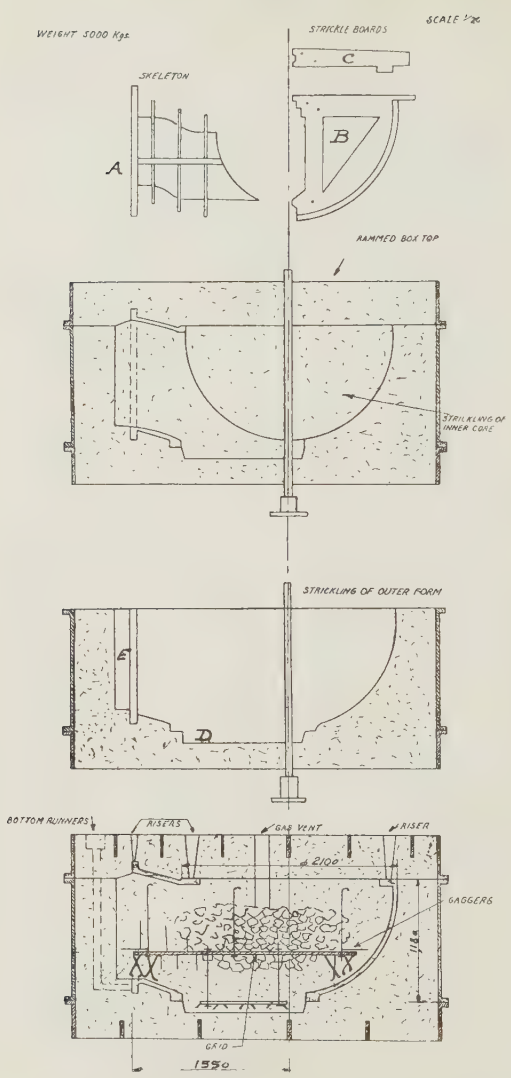


FIG. 9.—EXAMPLE OF COMBINED PATTERN AND STRICKLE MOULDING.

shape to the bend and determines its external dimensions, and (*b*) a strickle B cut to the external diameter of the bend, and the height of which, above the axis, is equal to the thickness of the boards of the templet A.

Moulding.—A half-portion of the bottom box is rammed, while marking the position of the lower half-flanges. The outline of the casting is traced with the aid of the templet, before ramming the top box. The lower tracing is marked on the top joint. The upper portion having been lifted and turned over, strickling is then effected with the scraper B, in accordance with the tracing, on the seating of the half-flanges, with the aid of the templet.

Coring.—Two half-cores are strickled on a bottom plate by means of the templet with which the mould has been strickled. The scraper has a slot *e*, the length of which is equal to the thickness of the bend. After stove-drying, the two half-cores are assembled.

This method of strickling the core is advantageous for simple and symmetrical forms. In the case of more complicated shapes the mould is lined with loam cakes having the thickness of the casting, whereby a core-box such as is shown in Fig. 8 is obtained.

Castings Moulded partly by Means of Skeleton Patterns and partly by Strickling (Filter shell, weight 5,000 kg.)

Patternmaking.—The preparation of a pattern and a core-box for a casting of this size would be very expensive. By applying the skeleton pattern and strickle method the patternmaking costs are reduced to a minimum.

The patternmaking equipment comprises:—(*a*) A skeleton pattern A for moulding the rectangular attachment; (*b*) a strickling board B for moulding the body of the casting; (*c*) a board C for striking up the internal flange; (*d*) a templet and a scraper for forming the bottom portion D, and (*e*) the lateral print in the core of the attachment.

Moulding.—After having rammed the bottom box, the moulder sets his board and places the skeleton pattern in position, with the aid of the drawing. The skeleton pattern is then filled with sand until it assumes, externally, the aspect of a pattern. The lateral coreprint is then placed in position and the ramming continued up to the joint. It is now necessary to strickle the false mould serving to build up the core. For this purpose the sand which is inside the skeleton is removed and a joint is made to correspond with the external face of the core, while strickling with the board B after removing its end piece. The print for the bottom is also strickled with the aid of the templet and the scraper.

After having completed the joint, the core is made in the usual way. The sectional drawing of the mould (Fig. 9) shows the arrangement of the grids and vents. On completing the ramming of the core the joint is made and the top box rammed up. The top is then removed, as also the parts forming the upper portion of the skeleton pattern. The internal flange is struck up with the aid of the board C.

The core is removed, as are also the parts forming the skeleton pattern, while the thickness of the body of the casting is strickled with the board B, fitted with its end piece. A section of the assembled mould is shown in Fig. 9.

Strickling with Threaded Spindle (Moulding a Winch Drum, weight 3,000 kg.)

The chief advantage of this special strickling method consists in the great saving effected in respect of machining. The grooves appear in the form of a spiral wound round the generatrices of the cylinder—a combination which enables them to be moulded with a plain metal scraper. The grooves to be reproduced being in spiral form, it is essential that the generatrix spiral should be made on the spindle. For this purpose a special strickle is formed round which the spiral is reproduced, on the lathe, with the pitch desired. A special collar is also required

carrying a finger which engages in the spiral thus formed on the spindle.

Patternmaking.—The equipment includes:—(*a*) A strickling board for the cope (this board also serves to form the tangential generatrix at the bottom of the grooves); (*b*) a board for strickling the bottom part; (*c*) a board for strickling the top part; (*d*) a board for strickling the core; (*e*) a metal scraper for strickling the grooves; (*f*) the loose pieces, hubs and ribs.

Moulding.—The loose pieces for the mould are made separately. The bottom part includes the moulding of the flange, ribs and hub, the work being carried out with the strickle and various boards.

The body is built up on a plate resting on the bottom joint, and is strickled as shown in Fig. 10. After strickling it is carefully stove-dried, and, after drying, slip loam is prepared for the moulding of the grooves, in such a manner as to prevent abrasion, during strickling, with the metal scraper.

The notch in the upper joint of the body should be noted. This notch permits the centring of the top box, when assembling the mould, by means of a band of loam having a corresponding diameter and section strickled on this box. The moulding of the top box is effected in the same way as in the bottom box. The core is strickled on a false mould, as shown in Fig. 10.

Strickle Moulding of a Propeller (Four-bladed Propeller, weight 5,250 kg.)

Propellers have two, three or four blades. The blades are strickled and finished consecutively round the hub. Each of them is covered by a special moulding box, a certain number of which are kept by foundries regularly supplying propellers. The hub is covered by a box supported on the boxes for the blades. The principle of the moulding is as follows: The axes of the blades having been traced (four in the example taken) and with the aid of the guides, to be described

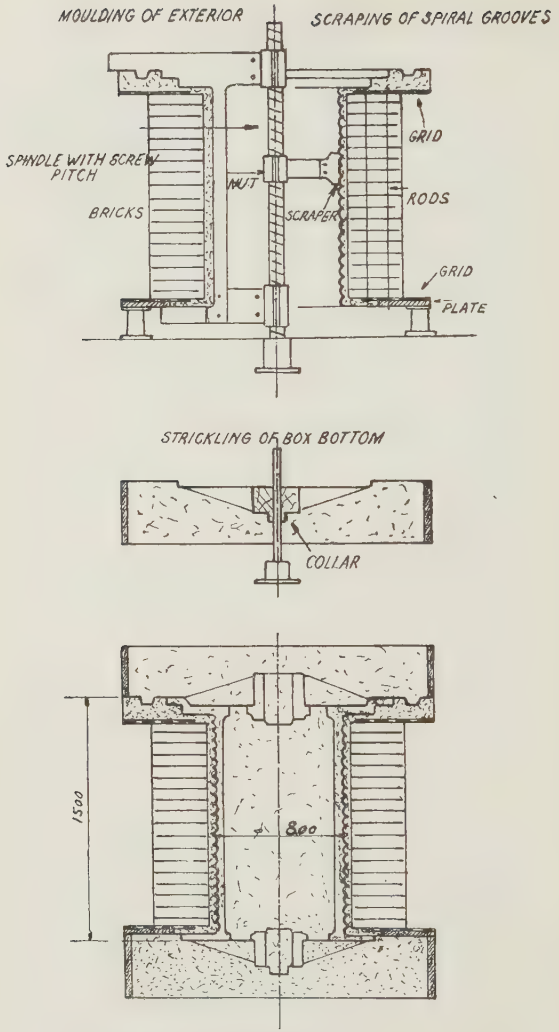

MOULDING OF EXTERIOR
SCRAPING OF SPIRAL GROOVES
SPINDLE WITH SCREW PITCH
BRICKS
NUT
SCRAPER
GRID
RODS
GRID
PLATE
STRICKLING OF BOX BOTTOM
COLLAR
1500
800

FIG. 10.

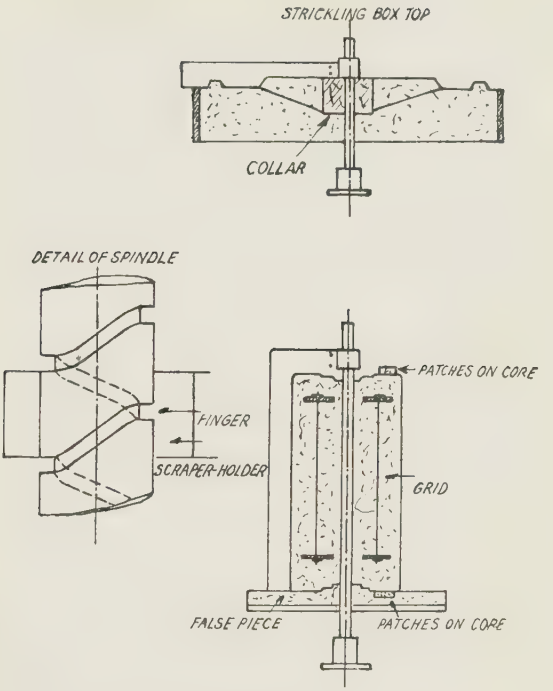


FIG. 10.—MOULDING OF A WINCH DRUM.

later, and after the ramming of the necessary quantity of sand, four curved surfaces are strickled in accordance with the drawing or the guide cone of the propeller. On these four surfaces the outline of the blade and the radii of the different sections are traced consecutively. These sections are cut to templet size in their proper position, the joints between them being made by hand.

Patternmaking.—The strickling tackle, socket and spindle are of the usual type in this case. It is advisable, however, to provide a balanced spindle with handle so as to enable the moulder

easily to make contact between the end of his board and the external guide as is shown in Fig. 12. The moulder prepares:—(*a*) A board for strickling the false hub; (*b*) a board A inclined at the angle of the generatrix of the blade; (*c*) four rigid sheet-metal guides 3 to 4 mm. thick, the hypotenuse (*x*) of which represents the continuation of the spiral in accordance with its pitch. These guides are curved, their radius being larger than that of the end of the blade so as to form an external guide; (*d*) a templet of flexible thin sheet metal ½ mm. thick, having the shape of the blade, upon which he traces very distinctly the middle line or axis of the blade, and also the various radii corresponding to the sections—the whole being done in accordance with the working drawing, and (*e*) the desired number of templets in a size corresponding to the various sections and of sheet metal 2 mm. thick, for example, curved in accordance with their respective radii.

Moulding.—After having placed the strickle board in position, the moulder strikes up the false hub in sand, loam, plaster or any other suitable material. Using a straight board, he strikes up an area 120 to 150 cm. wide encircling the radius to which the sheet-metal guides have been bent. This area permits the proper placing of these guides, *i.e.*, at their correct radius and division (four in this case) and exactly vertical to the given area. They are then secured in this position, by ramming with very strong sand inside and outside.

The moulder fills in the sand and rams it firmly between the guides and the hub. Having set up the board A, the moulder strikes up the generatrix surface of the propeller, while pressing the end of his board continuously over the plate guide. He now rams the four boxes with due care. These are to form the top parts of the mould. The moulder marks these boxes and finishes the upper portions. He then traces very carefully the axes of the blades, after which he proceeds to work consecutively on each of the blades and, finally, finishes them.

Placing on the sand the flexible templet C he traces with a stake the external outline, taking care to drive in a stake at each of the points where the various radii of the sections intersect the external outline of the blade. Having removed the templet he takes the quarter section, drives it in, with the rectilinear portion upwards, so that the ends of this section correspond with the first two stakes which he has just placed. He repeats this procedure with the $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$ and $\frac{15}{16}$ sections. Thus, marked in the sand, the incurvated shapes of the sections are obtained. On removing the sections, the moulder sprinkles

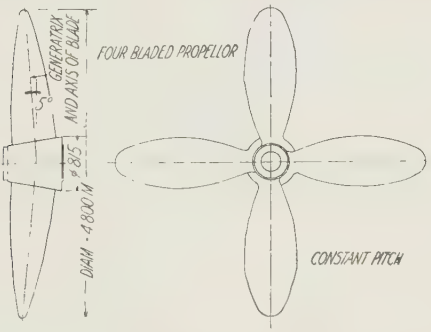


FIG. 11.—EXAMPLE OF CURVILINEAR MOULDING.

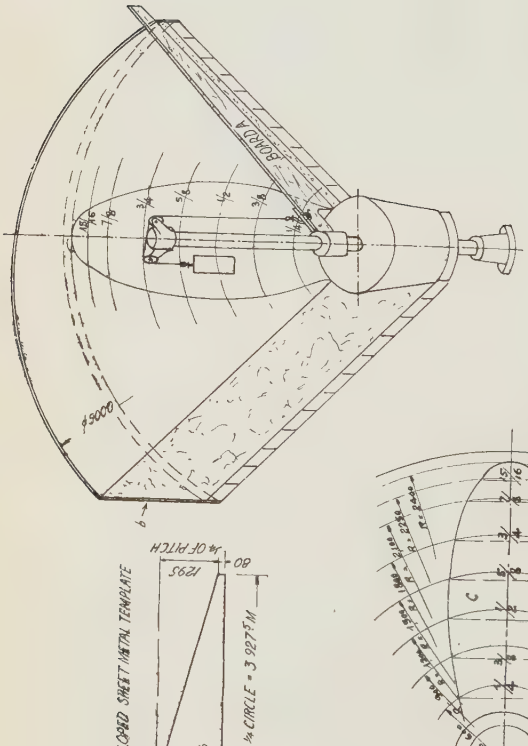
a small quantity of talc over this bottom mould so that it may show up clearly.

He then proceeds carefully to join, with the trowel, all these parts one to the other, so as to obtain the general form of the lower portion of each blade. When the blades are finished, he removes the false hub and assembles his mould.

Conclusion

As was intimated at the outset, the authors have not attempted to give a precise definition of the general practice of strickle moulding. Their British confrères are only too familiar with it already. On the other hand, they have instanced several cases where the application of

strickle moulding present characteristic features. Readers will perhaps be surprised at their having selected in every instance very simple castings



by way of example. They thought that by so doing the various working methods as applied to the example selected could be more easily followed than by means of complicated drawings.

Moreover, it would have been impossible to have given, within the very narrow limits of an ex-

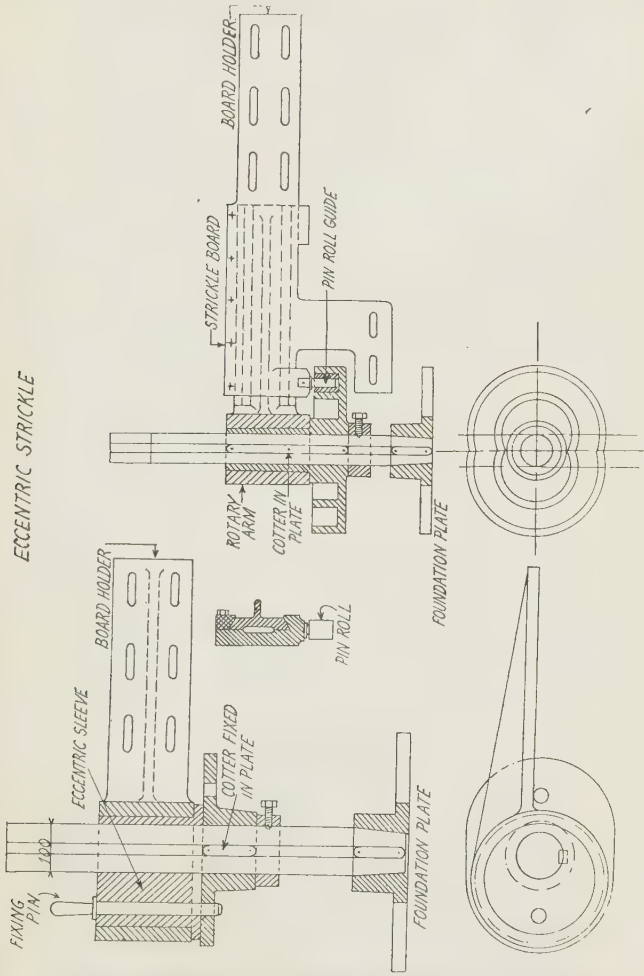


FIG. 13.—ARRANGEMENT FOR ECCENTRIC STRICKLING.

change Paper, all the details which complicated examples would have necessarily entailed.

Such as it is, this simple Paper may perhaps,

in respect to several points, arouse the attention of some of their confrères whose method of working differs from those of the authors. Any criticism which may be made of any particular method will be welcomed as being conducive to progress, and in this the authors will find their best reward.

DISCUSSION

J. J. McClelland regretted that it had not been possible for the authors to attend the Conference, and, at the outset, he wished to state that he could not understand why they should both begin and end their Paper by making apologies. It was a type of Paper which was necessary, and there was no necessity whatever to apologise for introducing its subject-matter for the consideration of the Conference. It would probably have been improved, however, if there had been fewer illustrations and a little more detail given in respect to each illustration. He would instance Fig. 2. He would like to know whether the brick work shown in the core, particularly in the upper portion, was a single row of bricks. There was no indication that it was otherwise. Personally, he did not think that a single row of bricks in the case of a core of such dimensions, with a casting weighing 12 tons, could resist the strain of the metal when the casting was made. There did not appear to be any kind of packing to strengthen the brick work.

Running Information Lacking

A formula had also been given for working out the area for runners, but it was not stated how the runners were to be placed nor how the metal was to be put into the casting. In one or two cases, reference was made to risers but there was no illustration as to how runners should be placed.

In regard to Fig. 3, was it to be understood that the loam brick referred to would be sufficient to counteract the contraction of the casting? It was not indicated whether there should

be any splitting of the lifting plate to comply with the contraction elements. Were the loam bricks relied upon to overcome the difficulty of contraction?

Fig. 7 appeared to indicate a somewhat expensive way of making the arms for the job. Why was not the ordinary practice of making cores sufficient? The authors of the Paper seemed to build up the arm in two halves in loam, which were secured together by backing plates for placing in position. Was not this a cumbersome method and could it not be more easily done by making cores?

Fig. 10 showed a method of making the core for a mould. There was no clear indication as to how the air was to be abstracted in casting, nor was there any illustration as to how the core was to be handled and placed in position in the mould. Further information appeared to be necessary in regard to those points.

Certain information was given with respect to top parts, but those were jobs which were not made in every foundry, as a matter of fact there were thousands of foundries where that kind of work was never seen. In order to enable the practical side of the industry to become well acquainted with that type of work more Papers of the kind should be read before the Institute. An item in connection with the propeller illustration required qualification with regard to the fractional figures shown along the centre line of the blade. It would be observed that it began near the hub where the thickest part of the metal was, with a quarter section, and at the extreme end of the blade, where the thinnest part of the casting was, it was fifteen-sixteenths. Without further explanation of what those figures meant, a student would probably be very much led astray.

There was a large number of practical men present at the Conference and he hoped they would take the opportunity of supporting his suggestion that more Papers of the kind submitted should be read before the membership of the Institute and for the benefit of the Industry

as a whole. He was quite convinced also that they would be of benefit and interest to the technical members of the Industry.

Strength of Core Bolts

Mr. J. Roxburgh said that when the Committee were contemplating the choice of suitable Papers for the Conference they felt, in Sheffield, that it would be desirable to have one of a practical nature. Therefore, they suggested to the *Association Technique de Fonderie* that such a Paper should be supplied by one of their members.

With reference to the Blackpot, Fig. 2, Mr. McClelland had suggested that one brick was insufficient for a job of the size mentioned. Personally, he was of opinion that one brick was sufficient. His own firm had made quite a number of castings of a similar nature, for example, chemical pots. In deciding the method which should be adopted for such a job a great deal depended upon whether one only or more were required.

Fig. 4 was quite a useful illustration of striking the back part of the core and it definitely saved the trouble of turning over a top plate. By turning the top plate over the core would be struck on the top plate. It would then have to be bolted up and rolled over, which caused quite a considerable amount of trouble in the foundry. By striking the back part, first of all, turning it over, and then building a single row of bricks, and bolting it up to the top plate, the trouble of turning the top part over was eliminated.

A point which occurred to him was that of the size of the bolt to be used for bolting up the core on to the top part. He had had an experience some years ago where the bolts used for bolting the core on to the top plate were not sufficiently strong, with the result that the core moved, and the casting was of unequal section. It was essential that the bolts used should be of sufficient diameter and sufficient strength to counteract any such possibility arising.

More or less orthodox methods were advocated in the Paper for the various jobs mentioned which did not really call for a great deal of discussion, but nevertheless the authors of the Paper were to be congratulated upon dealing with them in a very practical manner.

Split Crown Plates

Mr. J. Masters also wished to congratulate the authors upon the practical nature of their Paper. He noticed that the seating on the top plate was located on the wrong side. The remark had been made that there was not really much room for discussion of the Paper. Personally, he thought there was so much scope for discussion that in order to do the Paper full justice, there ought to be an extended session. Mr. McClelland had dropped a hint with regard to the making of the pan, and there was no doubt that, in making pans of the size indicated, the crown plate should be split in order to slide past the spindle. Personally, he had been responsible for hundreds of pots, and it was his practice to build the core on the plate and turn over the whole. He only used a 9-in. wall, which was buttressed in three places, in which three staples were cast for the supporting bolts, until it came to the crown plate. Those bolts were of sturdy dimensions, namely, 2-in. dia. It did not appear to be necessary to have six bolts on the inside of the core, and only three to hold them in position. The pressure on the casting referred to in the Paper was, approximately, 100 tons. He did not think the authors of the Paper would make a casting of that description with outside brickwork, without ramming it in afterwards, otherwise trouble would ensue. He used to cast these particular pots in prodded binders, without ramming them up. The top plate was quite 6 in. thick, there being a very good metal consistency.

With regard to runners, the authors of the Paper would have been well advised to have included some idea of their methods of running. He thought it must be agreed that the only way

of running them satisfactorily was from the top and all round the job. This was his own practice, and he obtained 100 per cent. good results, never having a cracked pot. The pots on the bottom ranged from 5- to 7-in. thickness, and, of course, the pressure was tremendous, yet there was not a single leak. It would have been better if the authors of the Paper had shown a different building of the core interspaced with the loam bricks to take off contraction stresses during cooling. He used to lift out the pots two days after they were cast and use the same outside structure again. There did not appear to be any utility in having three crown plates. One crown plate of suitable design was quite suitable to eliminate a fair amount of contraction in the mould and to obviate a large amount of extra work. He built his cores in the reverse position to the way the authors of the Paper built theirs, and turned them out without failure.

Mr. J. H. Pearce, in moving that a hearty vote of thanks be accorded to the authors for their most interesting communication, said that such a Paper was very welcome to the members of the Institute.

The President, in seconding the vote of thanks, did so with greater pleasure because he was a party, along with the Sheffield Council, in trying to obtain the Paper. Several of the members of the Sheffield Branch Council had made extensive tours on the Continent, and had formed the opinion that loam moulding was much more extensively practised in Continental foundries than in Britain.

The vote of thanks was carried by acclamation.

Written Communication

Mr. E. Longden, Manchester, wrote:—Whilst agreeing with the authors of the French Exchange Paper on strickle moulding that loam moulding has often been dealt with, it was not necessary to apologise. Only the fringe of the subject has yet been touched by the various prac-

tical foundry writers and we are indebted to the authors for presenting a sensible, practical paper.

The excellent Paper on "Castings" by Mr. Machin and Mr. Oldham emphasises the long practical and technical training necessary to produce large and complicated castings in loam.

Speaking broadly loam moulding certainly calls for a special type of skilled moulder. It was in this phase of foundry work that a sound knowledge of mathematics and drawing would be found to be invaluable.

The decision whether to produce a certain design of casting in loam by sweeping with strickles, or by the use of a skeleton pattern, a half pattern or a full cheap pattern and, in some cases, by cores, can only be truly arrived at by a foundryman of wide experience. It is very often a moot point whether loam pays.

Loam moulding is not always practised because pattern and moulding costs together are at the minimum. Many castings are made in loam because it is the safest form of mould for special and intricate castings of medium and heavy weight. Sometimes a mould may take several weeks to locate cores, or another mould may require considerable handling of both parts of the mould and cores. In such cases the strong loam mould withstands the wear and tear and movement of moulders and cores etc.

It is not the writer's intention adversely to criticise the Paper on strickle moulding, but to add just one or two points of view.

Cost Consideration

In many instances the cost of providing loam tackle is very often lost sight of by managements. If the cost of special loam plates and binders, etc., is properly identified with the cost of the job then all is clear, but this is, unfortunately, not always so. In many foundry yards huge piles of loam plates can be seen which have only the remotest chance of being re-used. Such tackle is idle and represents unused capital. In a large number of cases the cost of tackle has been merged in the general overhead charges

thereby masking the true cost of the casting made in loam. It is not uncommon to see a foundry make 60 tons of special moulding tackle to produce a 20-ton casting. In such a case it can be safely assumed that if the tackle is of no further use and is broken up as scrap a loss of £75 in metal alone is incurred if the normal pig iron and scrap mixture has been poured into the tackle. £75 will pay for much patternwork.

The authors' practice when producing the "Blackpot" is unduly expensive in the light of modern foundry practice. Advantage should be taken of portable drying stoves and it would then be unnecessary to transfer heavy moulds to the stove involving extra mould lifting plates and extra effort of moulding and handling.

In the writer's foundry castings similar to the "Blackpot" and large spindle castings for machine tools up to 22 tons are dried *in situ* by portable drying apparatus.

Pulley Moulds from Quarter Patterns

Strickle moulding of the 4-ton grooved pulley or flywheel would not quite commend itself to the writer as being the most economical method. Such a casting can be more accurately and cheaply made by a quarter pattern, or by making one core box to form the arms, a core box to make one twelfth of the rim and a half core box to produce the hub. To attempt to strickle grooves is rather a messy and tedious operation. Bores made from the section core box would carry the grooves very effectively.

Except with cores and protruding sections of moulds the writer does not permit the use of cinders in a loam mould. He finds that better drying is obtained by employing dry sand between the brickwork on the lower faces of a mould. Thoroughly dried loam is very porous. Binders on a confined lower face of a mould may act as centres for condensation of steam and so upset drying calculations and often create gas evolution during pouring, which impairs the metal and creates a fused-on condition of the

sand facing the casting. Venting and drying of the bottom face of a loam mould is far better if cinders are omitted trusting to the gas openings created by the drying process.

The authors of the Paper do not state how the " Blackpot " was gated. It can be assumed that the casting was poured through a series of top-drop gates. No other mould material but loam would safely withstand the impact of the metal.

The " Blackpot " casting is a case where strickle moulding is definitely the best practice and that both moulding and alternating cost is low and cannot be improved by any other method. After the first casting, production is extremely cheap, due to the retention of the mould brickwork for subsequent castings.

GERMAN PROGRESS IN PISTON RINGS, BRAKE DRUMS AND OTHER AUTOMOBILE CASTINGS

By W. A. Geisler (Member)

Presented on behalf of the Verein Deutscher Eisengiessereien.

[German Exchange Paper]

Piston rings for motor cars were originally made from sand cast grey iron bushes, but as requirements in respect of quality became more exacting, research was directed to finding better materials and superior foundry processes. With the object of obtaining a fine-grained, wear-resisting piston ring, the single-ring casting process as in American practice was introduced in Germany several years ago, and it is now an established fact that the single-ring has been almost universally adopted in Germany. Piston rings made by the single-casting process have only very small machining allowance, and the rings can be machined more economically than those made as bushes. This was not, however, the determining factor: much more important and decisive was the material improvement in quality as compared with those machined from cylinders[1].

Single-Cast Rings

Standard single-cast rings are not alloyed, and thus they satisfy in every respect the requirements for water-cooled motor-car engines. The steady increase in the efficiency of the engines and the continued development of the Diesel type and of air-cooled engines in general are, however, associated with a considerably higher loading of the piston ring, and every increase in efficiency means a further loading. Here the standard single ring reaches the limit of its capacity: the "efficiency reserve" is exhausted.

How can a ring with a higher efficiency reserve be obtained? The simplest and safest way

is by the addition of certain elements as alloys to the piston-ring material. Attempts have been made to impart a higher efficiency reserve to the rings by heat-treatment or by hardening, but it has been found that for a successful heat-treatment the ring has to be alloyed.

The alloying of single-cast rings is, however, beset with difficulties. For, in order to obtain a casting fit for machining, it is necessary that

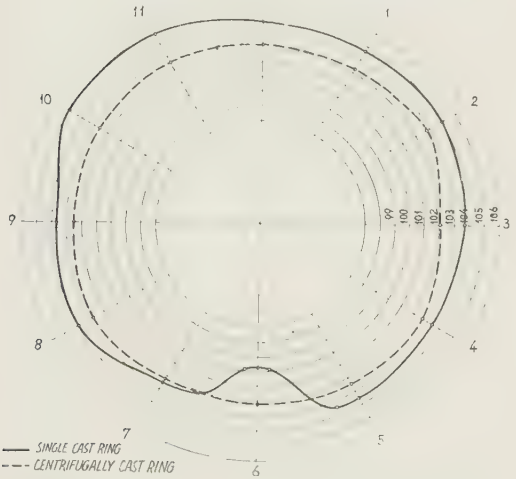


Fig. 1.—Rockwell (Scale B) Hardness Variations at Periphery of Piston Rings.

single rings, with their small sections of only a few square millimetres and high percentage of carbon, should contain 2.7-3.0 per cent. silicon. This, however, represents practically the softest cast alloy, as cast iron having a Si-content of over 3 per cent tends to harden again. Thus, if it be desired to improve the piston-ring material by alloying—and in this case, as explained further on, only carbide-forming or carbide-containing elements are suitable—the rings

are liable to become so hard, that they cannot be machined. According to the writer's observations, the addition of special elements as alloys is possible only to a limited extent in the case of single rings. Personal experience and tests have shown that the centrifugal casting process is much more advantageous in the case of alloyed piston rings. Here the rings are cast

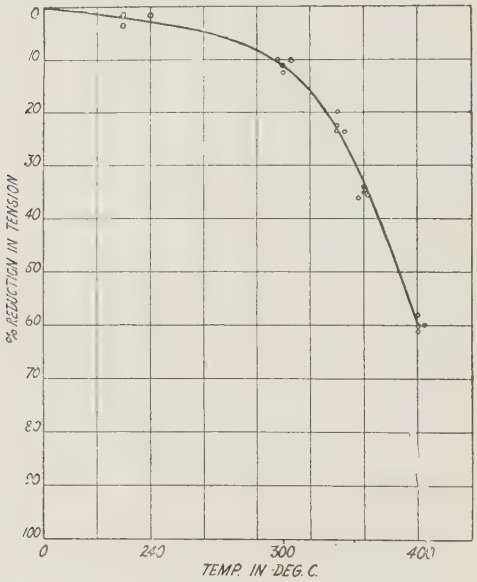


FIG. 2.—PERCENTAGE REDUCTION IN TENSION IN RELATION TO TEMPERATURE.

in the shape of a bush, from which the rings are obtained by machining. Although the centrifugally cast bush is made in a chill mould, the considerably larger mass of the bush—*i.e.* the lower cooling speed—naturally permits harder alloying, and therefore the addition of carbide-forming special elements no longer presents any difficulty.

Centrifugally-Cast Rings

Another not to be underrated advantage of the centrifugally cast ring is the uniformity of the material throughout the entire section (see Fig. 1). For the single ring, at least one gate is required; if the sections be small a riser is also necessary. At these points, however, the ring will remain liquid for a longer period and cool more slowly, so that it acquires a different structure and becomes softer. Rings which are out of truth and a rapid fall in pressure may be the result.

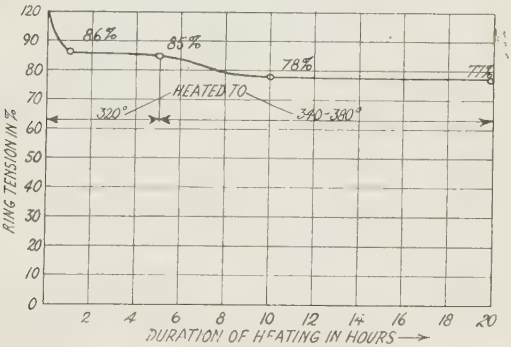


FIG. 3.—PERCENTAGE RING TENSION RELATED TO DURATION OF HEATING.

The writer holds the view that standard piston rings which are not subjected to excessive stresses can be produced most advantageously by the single-ring process. The many millions of single rings produced during the last few years in Germany, as also in America, are the best proof of this. For alloyed piston-rings subjected to high stresses, *i.e.*, rings having a higher efficiency reserve, such as those for use in Diesel engines and aero-engines, the centrifugal casting process appears to be better suited.

Addition of Special Elements

The special elements to be regarded as alloy constituents are those which are not usually contained in grey cast iron, *e.g.*, nickel

chromium, molybdenum and vanadium. These elements are added to improve the mileage, to ensure greater tensile strength and, especially, to increase the heat resistance of the casting. With normal alloys, the carbon content of single-

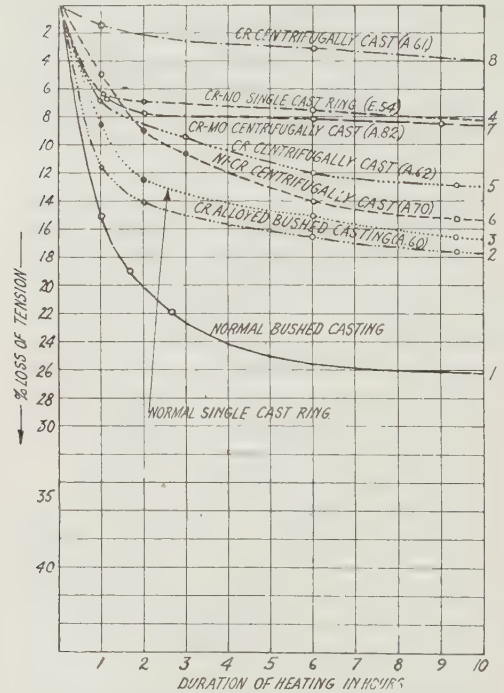


FIG. 4.—HEAT-RESISTING PROPERTIES OF PISTON-RING MATERIALS RELATED TO THE LOSS OF TENSION.

cast rings is kept fairly high, *i.e.*, about 3.6-3.8 per cent., so as to obtain a medium-coarse graphite formation, as this, according to recent experience and confirmatory tests, ensures the highest resistance to wear [3 4 5]. Eutectic graphite generally contains patches of ferrite,

which prove highly detrimental to the durability of the casting. The formation of eutectic graphite must therefore be avoided.

As the result of numerous experiments the fact was confirmed; that the mileage of a piston

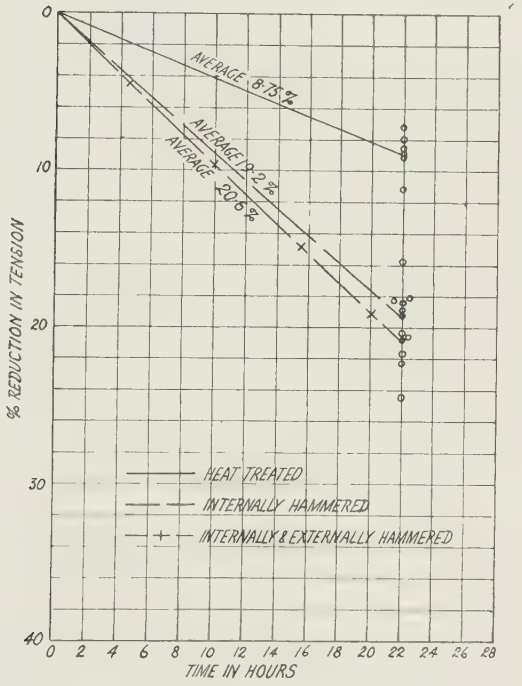


FIG. 5.—REDUCTION IN TENSION OF HEAT-TREATED AND HAMMERED PISTON RINGS AFTER 22 HOURS' HEATING AT 300 DEG. C.

ring is improved by a well-marked phosphide network [6 7 8 9]. But as phosphorus reduces the tensile strength of the casting, limits are set to its use as an alloy. The manganese content is kept at the highest limit, from 0.8-1.0 per cent. on an average.

It would be beyond the scope of this Paper if the machine-finish of the piston rings was discussed. It is worthy of note, however, that as far back as 1918, J. E. Hurst [10] found that the usual machining condition of cast-iron castings has a decisive influence on their wear-resisting qualities, the wear generally being all the less, the finer the finish machining condition. The correctness of this view was confirmed in Germany by Th. Klingenstein [11]. As a result, the demand for ground piston rings is continually increasing.

Reverting to the question of material, it was formerly held that in order to render a piston ring resistant to wear it was only necessary to provide for an essentially pearlitic structure.[12] Experience, however, has shown that pearlite alone is not the determining factor. The advantage of a phosphide network has already been mentioned. Moreover, a fine-grained and, above all, *resistant* structure has proved to be necessary. For piston rings in internal-combustion engines are now subjected to temperatures which are often very considerable, with the result that the tension of the rings is seriously affected if the structure is not resistant.

Tests at Elevated Temperatures

The examination of a single ring (Fig. 2) showed that at each heating of 24 hrs. duration and at increasing temperature, a constantly increasing fall in tension occurred. Up to 300 deg. C. there was a tension drop of about 10 per cent., which may still be regarded as quite tolerable. Above 300 deg. C., however, the pressure falls rapidly, the loss at 400 deg. C being already about 60 per cent.! When the pressure is greatly reduced, however, a piston ring no longer fulfils its allotted function, *i.e.*, to maintain tightness. The rings either permit the passage of oil or allow the hot gases to sweep past them, so that the oil film is destroyed and the rings wear out rapidly or seize.

The resistance of piston rings to heat—and here, according to recent measurements, temperatures of 250 to 350 deg. C. and sometimes

even higher are encountered—depends on the resistance of the carbides contained in the cast iron, as also on their size and arrangement. Pearlite consists of a lamellar arrangement of iron-carbide (cementite, Fe_3C) and ferrite.

Effect of Special Elements

The formation of the pearlite is also of importance; coarsely lamellar pearlite (bush casting) is much less resistant than finely-lamellar pearlite or sorbite, such as is met with in

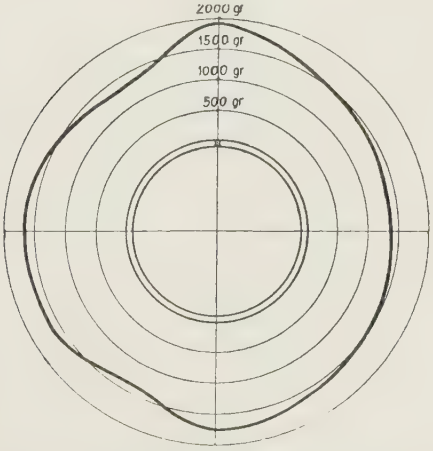


FIG. 6.—RADIAL PRESSURE CURVE OF SINGLE-CAST PISTON RING HEAT-TREATED.

extremely fine-grained cast iron (single or centrifugal casting). The resistance of the carbides to heat can be materially improved by the addition of carbide-forming or carbide-promoting elements. These include chromium, molybdenum, vanadium, tungsten, arsenic, antimony and bismuth.[13] In personal experiments, chromium, vanadium and, particularly, molybdenum have so far given the best results. Experiments with tungsten are still proceeding.

Chromium is the most effective of the carbide-forming and carbide-promoting elements. Even the addition of only a few tenths per cent. of chromium causes a substantial increase in the heat-resistance, whilst at the same time producing a higher degree of hardness and tensile strength. The action of chromium is so sharp, however, that it can only be added, alone, in very small quantities. In most cases chromium is added in combination with nickel, which has the opposite, *i.e.*, a graphite forming, effect. Addi-

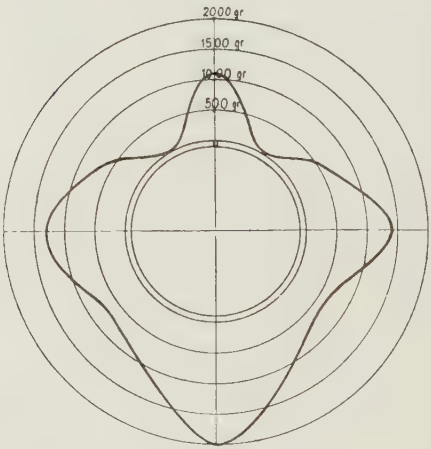


FIG. 7.—RADIAL PRESSURE CURVE OF SINGLE-CAST PISTON-RING—HAMMERED.

tions of molybdenum gave very good results, as this element has not the potency of chromium, but yet promotes in a remarkable degree heat-resistance and tensile strength.[13] [14] According to the writer's observations, in numerous experiments, nickel additions alone, even with the reduction of the silicon content, yielded no advantages whatsoever, either as regards the mileage or the heat-resistance of piston-ring material. For the same reason, other graphite-forming elements, such as titanium, copper and

aluminium, proved equally unsatisfactory. Cobalt had a neutral action, within the limits in which it was added to the cast iron.[13 15]

In order to determine their heat-resisting properties, the finished piston rings are placed in a cylinder of suitable diameter and heated for a given period, generally 24 hrs., at 200, 300 or 400 deg. C. The loss in tension in percentage of the initial tension may be regarded as the

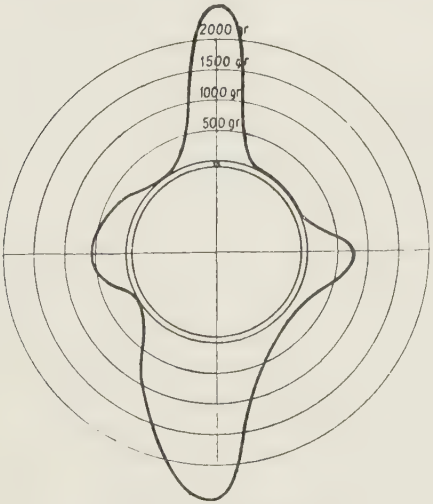


Fig. 8.—Radial Pressure Curve of Eccentrically-shaped Piston Ring.

measure of the heat-resistance. It is interesting to observe that a piston ring heated at a certain temperature (*e.g.*, 320 deg. C.) suffers a fall in pressure after only a short period, but then maintains a constant effect, that is to say, that the piston ring, once it has suffered the tension drop corresponding to the temperature, retains its tension in relation to these temperatures, *i.e.*, it remains resistant to heat. When heated at higher temperatures (*e.g.*, 340 to 380 deg. C.,

a further fall in tension then occurs, which again follows a nearly straight line, as is shown in Fig. 3.[2] The dependence of the heat-resistance upon various alloy constituents is shown in Fig. 4, the high value of the chromium and molybdenum alloys being immediately obvious. The test temperature was the same for all rings, namely, 340 deg. C. Similarly, all test rings had the same dimensions.

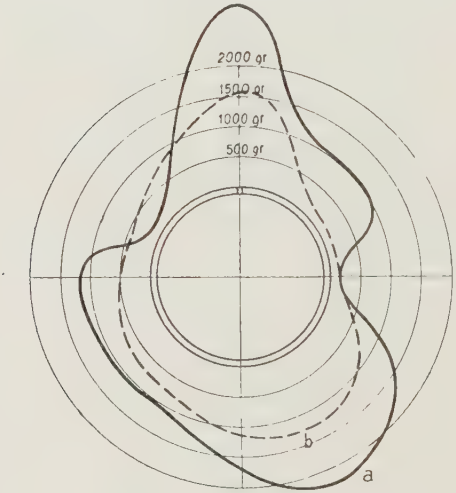


Fig. 9.—Hammered Bushed Piston Ring after Lightly Grinding. (*a*) Radial Pressure Curve before Grinding, and (*b*) after Grinding.

Tension Losses in Piston Ring Types

Curve 1 shows the fall in tension in a standard bush-cast ring. On the addition of chromium the heat resistance was found to be materially improved (Curve 2). Curve 3 indicates the tendency of the tension in a standard unalloyed single-cast ring. The addition of molybdenum (Curve 4) brought about a quite

considerable increase in the heat resistance. Curve 5 shows the tendency of the tension in a centrifugally-cast material alloyed with chromium. In addition to chromium, Curve 6 contains nickel and yields a better initial heat resistance, this being perhaps due to the finer grain size; but in its further course the tension falls very rapidly and proves to be less favourable than material No. 5. Curve 7 represents

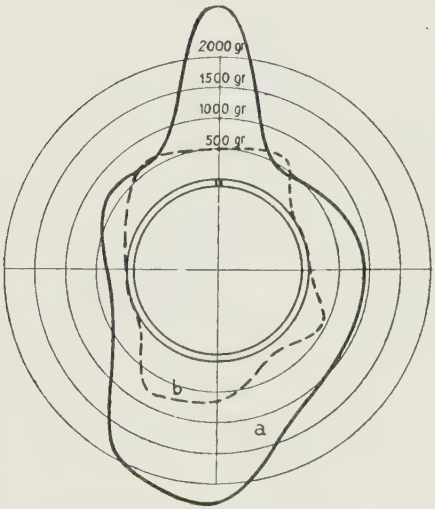


Fig. 10.—Hammered Bushed Piston Ring. (*a*) Radial Pressure Curve of New Rings, and (*b*) Curve for Rings after $\frac{1}{2}$-mm. Wear at Walls.

a centrifugally-cast material alloyed with chromium and molybdenum. Curve 8 represents the optimum hitherto obtained; a centrifugally-cast material with a high percentage of chromium.

Method of Applying Tension

Another factor not without influence on the heat-resistance of a piston ring is the manner

in which the tension is applied (Fig. 5). As the result of numerous experiments it has now been possible to demonstrate that a thermally-expanded piston ring is far superior to a hammered-in ring of the same material, this superiority being all the greater according to the height of the running temperature and the fineness of the grain of the piston-ring material.

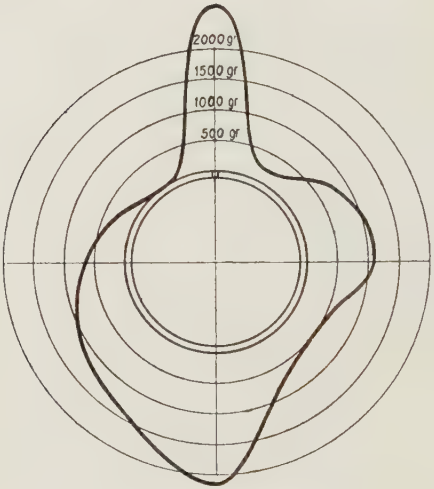


FIG. 11.—HAMMERED BUSHED PISTON RING. RADIAL PRESSURE CURVE OF A RING AFTER DOING 625 MILES.

A further advantage of the thermally-expanded piston-ring is the uniform distribution of radial pressure over the whole periphery, as will be seen by comparing the various "Radial pressure curves" (Figs. 6-11) [1]. These curves were obtained by measuring the radial pressure in a piston ring at 16 points on the periphery, and then connecting these points to circle-ordinates. It is clear that, theoretically, these curves must

have a circular shape and that the characteristic curve of a ring becomes poorer in direct proportion to the deviation from the circular form.

Radial Pressure Curves

Fig. 6 shows the course of radial pressure in a heat-treated expanded single ring. The course of the curve approaches fairly closely to the circular form. In Figs. 7 and 8 are shown the curves of a hammered-in piston ring and a ring made by the eccentric process respectively;

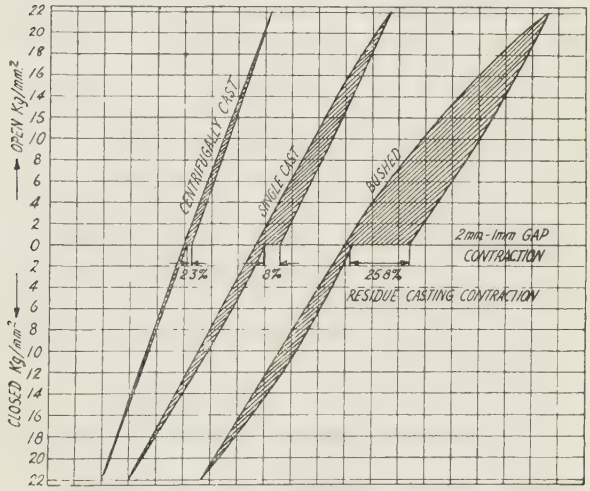


Fig. 12.—Hysteresis Curves of various Piston-Ring Materials.

these curves diverge widely from the circular form (see also p. 134 of reference [16]). It may be argued that during running the rings adapt themselves: they "run themselves in," so that the points of high radial pressure are soon worn down and a balance is quickly established. To verify this, the radial pressure measurements were also made upon worn rings, the wear being brought about artificially by grinding them slightly (Fig. 9); furthermore, really worn

rings were tested (Fig. 10) and, finally, the wear was brought about by allowing the rings to "run themselves in" (Fig. 11.) These tests confirm the fact that "running-in" by no means completely equalises the differences in pressure. It mitigates them to a certain extent, but the original characteristic curve is retained. Thus the old experience of the piston-ring manufacturers is confirmed: that eccentric rings do not become round even after repeated grinding.

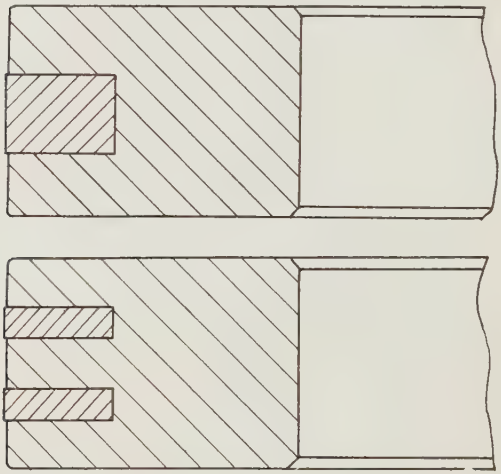


Fig. 13.—Piston Rings with Bronze Liners.

Testing Methods

In Germany efforts are being made to discover a definitely reliable method of testing piston rings. Such useful specifications as the "B.S.I. 5004 and 4K6 for aircraft material" do not exist in Germany. Wear-testing machines have so far proved a complete failure and can never lead to an impeccable result. An effort has therefore to be made to establish singly the various factors which, together, yield good mileage properties. These factors include: the chemical analysis, the microscopic structure,

physical properties, *e.g.*, tensile strength, permanent set, heat-resistance, etc. The modulus of elasticity has only an indirect influence on the mileage properties.

On comparing the above factors it is found that the characteristic curve of a piston ring is rather narrowly limited, but an inference may be drawn as to the effectiveness of a piston ring for the purpose required of it.

In this connection, it should be pointed out that in judging a material its hardness is a thoroughly unreliable guide. Founders can to-day produce grades of cast iron the properties of which vary greatly, although the

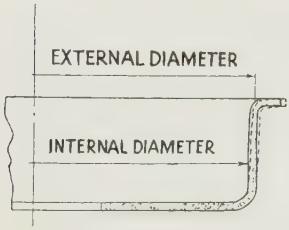


FIG. 14.

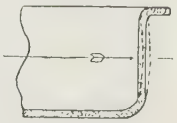


FIG. 15.

hardness is the same, that these characteristics cannot be relied upon.

A rapid survey of piston-ring material enables us to determine the so-called "piston-ring hysteresis" (Fig. 12). As ordinate, the bending stress per sq. mm. and as abscissa the width of a gap in a piston ring originally free from stresses are taken. The ring is then subjected to pressure, for closing the ends, up to a given maximum pressure, generally 22 kg./mm.^{2} (14 tons per sq. in.), after which the pressure is brought back to zero and the ring is then loaded in the opposite direction, *i.e.*, for opening under the same loading stress, and the pressure again released. The curve does not then return to the original point. The distance from

the starting point indicates the extent of the "permanent set," which is best expressed in percentages of the maximum gap width. The area enclosed by the hysteresis curve corresponds to the loss of tension in the ring. The degree of inclination in the curve depends upon the modulus of elasticity. The higher the modulus the steeper will be the hysteresis curve. The graphs obtained in this investigation afford very valuable indications as to the nature of the material which, in conjunction with the chemical analysis and the examination of the structure, yield a complete picture.

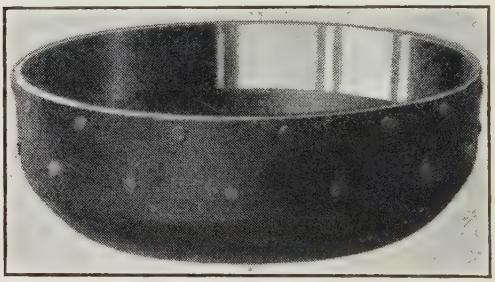


FIG. 16.—STEEL BRAKE DRUM FITTED WITH CENTRIFUGALLY-CAST LINER.

Efforts have recently been made, both in America and Germany, to obtain exceptionally durable and wear-resisting piston rings by embedding bronze rings in cast-iron rings in such a manner that the bronze will take care of the actual running conditions, whilst the cast iron will afford the resistance to heat (Fig. 13). In Germany, however, no appreciable advantages have been gained by these rings.

Cylinder Liners

In Germany, moreover, the view is being increasingly adopted that for a good piston ring a suitable cylinder surface is necessary.[2] This is shown by the development of the cylinder

liner. In German engines—petrol as well as Diesel—cylinder liners are being used to an increasing extent.

It may be mentioned, however, that hardened liners have so far not been in great demand in Germany; while, on the other hand, completely satisfactory results have been obtained by the use of suitably-alloyed, centrifugally-cast liners. While, for ordinary engines, centrifugally-cast materials containing a slight proportion of chromium alloy were found thoroughly satisfactory; centrifugally-cast liners, alloyed with

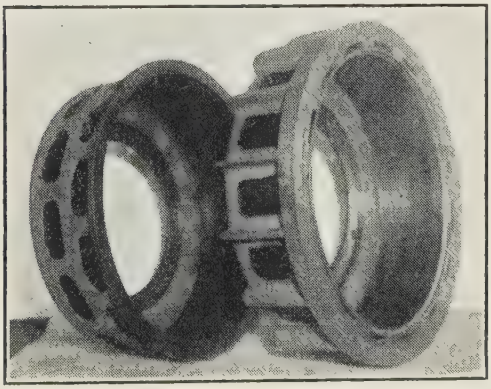


Fig. 17.

chromium and molybdenum, are preferred for Diesel engines or engines subjected to high stresses, as being more advantageous.

There was a time when it was prophesied that cast iron would be gradually ousted by steel or malleable castings. Since then, cast iron has provided many surprises; from the unreliable cast iron of an earlier period noteworthy high-grade materials have been created. In respect of resistance to wear, minimum sensitiveness to notching and shock-absorbing capacity, cast iron is immensely superior to steel.

Owing to its advantages, high-grade cast iron is being increasingly used in motor vehicles. One need only mention the crankshafts and camshafts of alloyed cast iron which are being adopted to an ever-increasing extent.

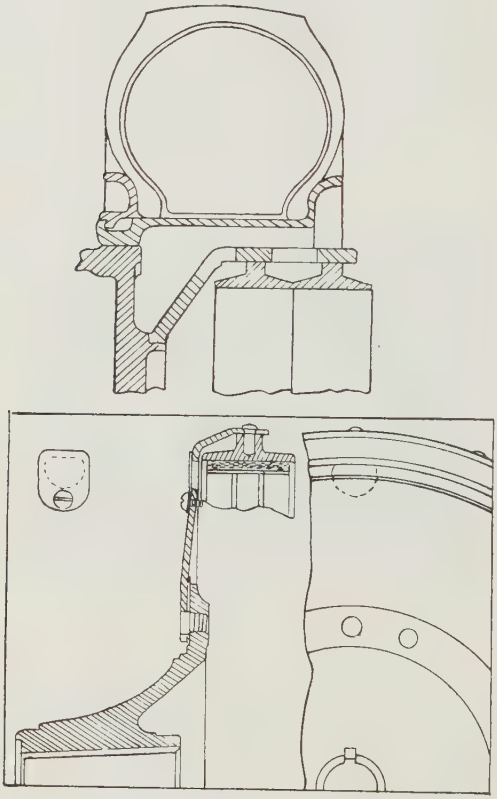


FIG. 18.—HOLLEY BRAKE DRUM.

Brake Drums

In the case of brake drums cast iron has already given excellent results. For quite a number of years the standard, pressed-sheet-steel drums were considered adequate, but as improve-

ments, necessitated by the increase in speeds, were introduced in brakes, it was felt that a better material was needed for the brake drums. The great disadvantage of sheet-steel drums is that they expand considerably when subjected to heavy brake pressure and superheating and become out of truth. In most cases this expansion is very irregularly distributed, and occurs mainly at the flange diameter (bell-mouth effect, Fig. 14), or else the braking surface sags (barrel effect, Fig. 15). Moreover, the brake lining frequently tears bits of steel out of the braking surface; these pieces remain adhering in the lining and cut furrows in the braking surface which, once formed, quickly become deeper and

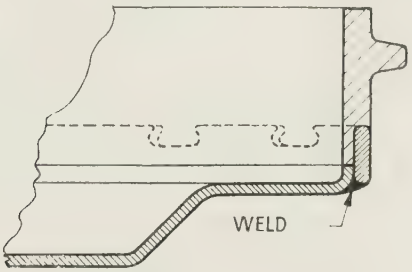


Fig. 19.—American "Centricast" Brake Drum.

cause rapid wear. In addition, sheet-steel drums, which are very thin *per se*, are highly resilient, and it has been found that over 50 per cent. of the pedal stroke is expended in overcoming this resilience.

In the search for a material which should not show the above-mentioned disadvantages it was soon proved that cast iron was far superior to all other materials, including cast steel, improved sheet-steel, etc. Owing to its rigidity, the cast-iron drum never loses its shape even when subjected to maximum heating, and thus it maintains a uniform braking effect. With cast iron the braking effect is very powerful and instantaneous and, above all, very uniform,

as no resilient effect is set up, so that cast iron owing to the properties inherent in the material itself, *e.g.*, graphite striæ and higher friction coefficient, constitutes a very good braking surface. As cast iron is highly resistant to wear, brake drums made of this material have a much longer life than steel drums.

The cast-iron drums has, however, one great disadvantage. In order to ensure adequate tensile strength it has to be made considerably heavier than a sheet-steel drum of the same size. Its use was therefore limited for the time

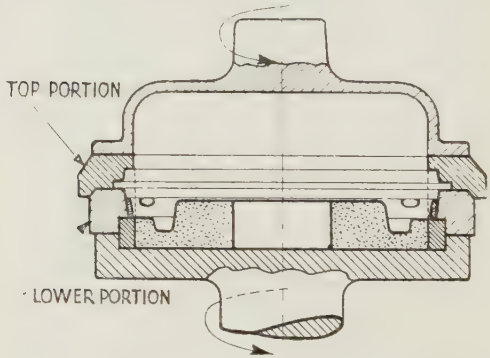


FIG. 20.—VERTICAL CENTRIFUGALLY-CAST BRAKE DRUM WITH INSERTED STEEL COMPONENT.

being to heavy, slow-running lorries, and for these it has proved satisfactory in every respect, particularly in the United States, during the last 8 or 10 years. Although the properties of the cast-iron brake drum have been substantially enhanced by the improved quality of the metal, the use of highly developed melting processes and the addition of chromium, nickel or molybdenum, none of the many brake drums which have appeared under their various trade names is able to show even approximately the low weight of the sheet-steel drum. This was, however, one of the main factors which made

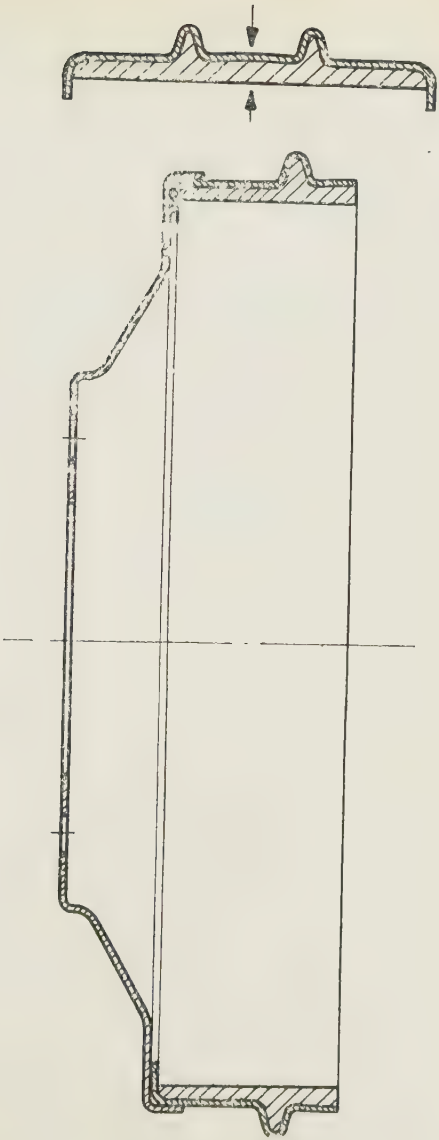


FIG. 21.—"CENTRIFUSE" BRAKE DRUM.

the use of cast-iron drums impossible for high-speed vehicles.

Combined Iron and Steel Drum

A happy combination of the properties of sheet steel and those of cast iron was incorporated in the Centrit brake drum made by the author's firm, Messrs. Alfred Teves, of Frankfurt-am-Main, which appeared in Germany about two years ago [2]. Before giving a detailed description of this drum, a brief summary showing the evolution of the combined steel and cast-iron brake drum should be of interest to the founder, as also to the motor engineer, particularly as such a summary has not hitherto, so far as the

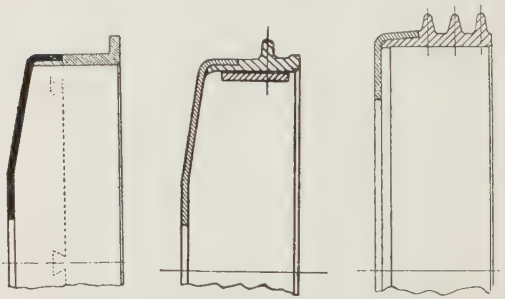


FIG. 22.—"CENTRIT" BRAKE DRUMS.

author is aware, been available. It is expressly pointed out, however, that this summary does not claim to be complete; on the contrary, only a few practical tests of outstanding interest will be mentioned.

(1) The first experiments with combined drums appear to have been made in England, where worn steel drums were bored out and then provided with a centrifugally-cast liner as is shown in Fig. 16 [17]. Apart from the fact that this process is very expensive, it was impossible to adopt this drum for quantity production, owing to its poor transmission of heat. The heat engendered by braking accumulates in the liner and is transmitted only very gradually to the outer steel casing. This gave rise to

two disadvantages: Firstly, the liner, under continuous brake loading, becomes too hot, so that cracks appear on the braking surface. Secondly, owing to the permanent differences in temperature the liner works loose, so that if it were not secured with copper rivets it would rotate within the steel drum.

(2) In order to facilitate the heat transmission of the liners, an American concern provided the outer steel casing with openings and cooling ribs, but no material improvement was thereby effected. The brake drum shown in Fig. 17 had the additional disadvantage of comparatively heavy weight.

(3) Early in 1930 an entirely new combination was evolved in America. This was the Holley brake drum (see Fig. 18), which consisted of a sheet-steel holder with a brake ring of approximately T-shaped section fixed therein.[18] It was claimed for this combination that it entirely eliminated the "bell-shape" effect; that its weight exceeded by only a little that of a sheet-steel drum; and that it enabled an excellent transmission of heat to take place. The brake ring was cast by the well-known Holley "permanent-mould" process and treated accordingly. It is known that this casting is nearly 100 per cent. ferritic, but such cast iron is not resistant to wear.

(4) In 1931, in Newark, N.J., a process became known in which worn Ford sheet-steel brake drums were provided with a centrifugally-cast rim of cast iron. These drums were called "Centricast" brake drums, a name borrowed from the English, but they had nothing to do with the English firm. The drum consisted substantially of a cast-iron rim, with an inserted ring of steel as shown in Fig. 19. The steel ring was provided with semi-circular notches in order to prevent its working loose. As will be seen from Fig. 19, the back of the old Ford drum was electrically welded on to the steel rim. The process used for the pouring of the steel rim is, owing to its unique character, sufficiently interesting to deserve elucidation.

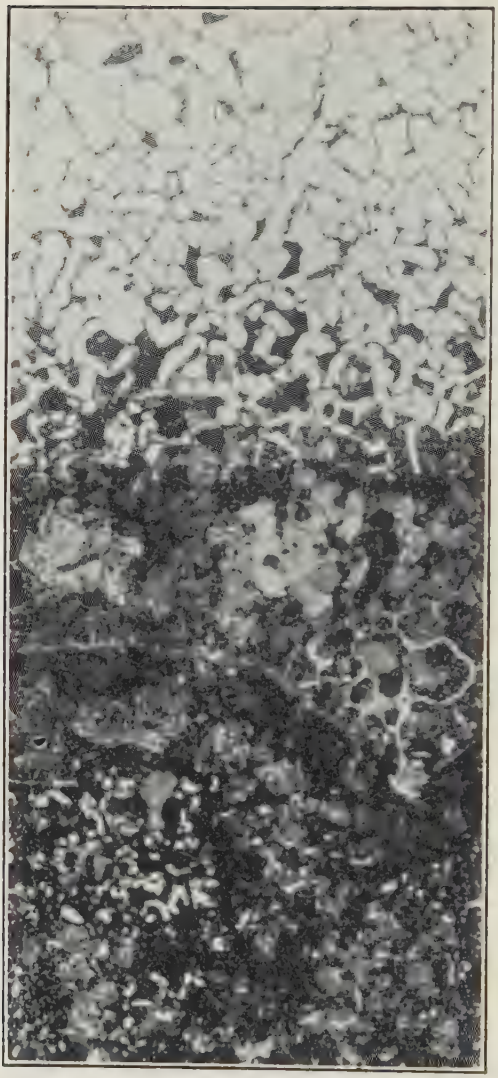


FIG. 23.—PHOTOMICROGRAPH OF WELD BETWEEN CAST IRON AND STEEL, ETCHED. × 200.

In the mould rotating about the vertical axis (Fig. 20) was located a revolving gate (Rille) of graphite or fireproof brick.[9] The flat iron, welded to a closed ring, was placed in the cast-iron mould, and while the machine was standing the pouring gate was filled with molten iron. By connecting the motor, which was coupled

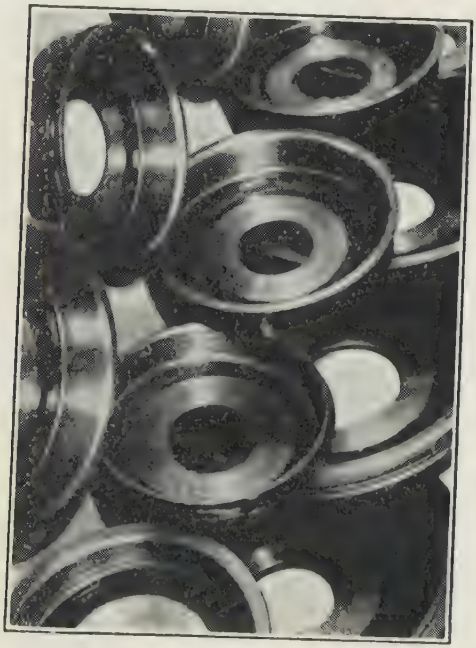


FIG. 24.—"CENTRIT" BRAKE DRUMS.

directly to the mould, the iron was then thrown out of the gate to meet with the full force of the 900 to 1,000 revolutions of the mild-steel band, which was instantly heated to white heat and welded to the cast iron. As the cast-iron rings solidify white (cementitic) at the edges, owing to the iron mould, they had to be heated until soft before being further worked up.

(5) The " Centrifuse " drum—a further type —had an extraordinary success in America.[20 21 22] This might be described as a " multiple assembled " drum. Into a ring previously heated to bright red (Fig. 21) a given quantity of iron was poured, in accordance with the centrifugal-casting process. After cooling, the duplex ring thus obtained was divided and then fixed to a suitable disc by spot welding.[23] Thus there is again, substantially, a cast-iron ring located in a mild-steel drum. The essential difference between the " Centrifuse " brake drum and the English type, with liner, mentioned under (1), is that the heat transmission in the former is incomparably better. This is due to the fact that steel and cast iron having been united by welding a far-better transmission of heat from cast iron to steel is obtained. In many millions of brake drums the " Centrifuse " drum has given excellent results.

For European conditions, however, the " Centrifuse " brake drum is too dear. First of all the casing has to be rolled out of one piece, so as to enable it, as the short-circuited secondary coil of a transformer, to be brought to bright-red heat in 15 to 20 seconds and thus render possible the welding-on of the cast iron. In addition, the back guard of the drum has to be made separately and then fixed to the brake rim. The equipment required for this purpose is exceedingly comprehensive and expensive—to say nothing of the cost of the drum itself. The vast numbers produced in America have rendered possible the adoption of this process.

The " Centrit " brake drum, made in Germany, represents a further improvement in the combined steel and cast-iron brake drum. Here simplicity of manufacture and appropriate shaping go hand in hand (Fig. 22). The drum consists essentially of two parts: the sheet-steel back—the flange of which is provided with dovetailed-shaped notches so as to facilitate intimate welding and obtain increased security—and a cast-iron rim. As will be seen from Fig. 23, the weld between cast iron and steel is a thoroughly

intimate one. A real fusion takes place and, as is clearly shown, the carbon in the cast iron penetrates into the steel to a considerable depth. The effect is a weld between the two metals which may be compared to a real merging, whereby both parts are connected.

Thus it is only necessary to make one pressed component. This pressed component does not require to be heated, nor is it necessary to effect a subsequent welding of the back on to the brake rim. The exceptional advantages of the "Centrit" brake drum won the unanimous appreciation of experts, and a number of the leading German motor-car manufacturers have adopted it for quantity installation in their vehicles. It is interesting to note that the advantages of the "Centrit" brake drum are being utilised not only for large vehicles but also for small cars, *e.g.*, the "Adler Trumpf Junior," in which it is installed as standard drum. This shows that the combined centrifugally-cast brake drum need not be regarded as a prerogative of large, costly cars. It may be added that, as compared with the all-cast-iron drum, the combined drum not only possesses the advantage of greater reliability and lightness, but is also much more advantageous as regards machining. In the all-cast-iron drum the back requires to be machined on both sides, but this is not necessary in the case of the steel back of the "Centrit" drum. Furthermore, when riveting or screwing this drum on to the wheel hub there is no danger of its splitting, as so often happens in the case of cast-iron drums, particularly where it is a matter of quantity production on a considerable scale so that very great care cannot be counted upon.

"Centrit" brake drums have been, and are being, produced in large quantities in Germany (Fig. 24), and the experience of the past two years justifies the presumption that this type of drum will also find favour in other countries. In this connection, it should be mentioned that a leading foundry for centrifugal castings in England is already being equipped for the production of the "Centrit" brake drum.[24] The

advantages which had been claimed for the "Centrit" brake drum have been fully realised in the large numbers which have been installed in the last two years. And when it is added that not a single case is known in which a drum has been fractured, this goes to show the exceptional reliability of this brake drum.

The author wishes to express his indebtedness to Dr. Teves, of Alfred Teves, G.m.b.H., Frankfurt-am-Main, for permission to publish the results referred to in this Paper.

DISCUSSION

Mr. J. E. Hurst said he was gratified to be able to state that the author of the Paper was his personal friend and that he was present at the Conference. In addition to being a member, and the accredited representative, of the German Foundrymen's Association, he was also a member of the Institute. He had had the pleasure, upon a number of occasions, of seeing Mr. Geisler's plant and installation, together with his research laboratories. They were all extremely well equipped, and investigations were carried out with a thoroughness which was characteristic of work done in Germany.

Superiority Claimed for Centrifugally-Cast Rings

Mr. T. R. Twigger wished to congratulate Mr. Geisler upon the excellence of his Paper which was particularly complete. To him, personally, being intimately connected with the making of piston rings and similar castings, the Paper was of very great interest. He noticed that Mr. Geisler made a comparison between single cast rings and rings made from centrifugal castings. Most of them would agree, from practical evidence in various countries, that the single casting in ordinary automobile practice did give satisfactory service, but to those of them who had been particularly concerned with the development of centrifugal castings it would be very gratifying to learn that for high efficiency piston rings required to stand up to exceedingly hard conditions the centrifugal casting offered much better scope. A point which Mr. Geisler

did not appear to mention was the considerable difficulty experienced when dealing with rings of very narrow width, say $1\frac{1}{2}$ m.m. as individual castings.

He understood that firms in various countries who advocated single cast rings had experienced that difficulty, and that for such narrow rings they found it necessary to use pot castings.

Cylinder Wall Pressure

The work which interested him most was that relating to the heat resistance, as Mr. Geisler expressed it, of piston rings, namely, the resistance to the setting of the ring under working temperatures. He had been carrying out work in regard to that point for at least two or three years upon lines very similar to those described by Mr. Geisler. Broadly speaking, the results confirmed those mentioned in the Paper. The loss of cylinder wall pressure on piston rings could be extremely serious, particularly in high-duty engines of the aircraft type. It was difficult to lay down what factors were responsible for this closing in or loss of pressure. The trouble was probably intimately connected with creep phenomena. From a practical point of view the tests carried out by Mr. Geisler in loading the rings in a gauge and heating them up for various periods was a very good way of testing different piston ring materials. The factors which entered into it such as the radial pressure of the rings, the temperature, and the time, which were often variable in actual engines, could be kept under control in laboratory experiments. It was not by any means an easy matter to lay down a formula; the creep continued over comparatively long periods of time. No doubt Mr. Geisler would still further continue with his research work. Mr. Twigger said he was very interested to learn that the rings which were formed by heat-shaping were better. This confirmed his own experience, personally. The loss of pressure in service on rings formed by heat was normally about half that on a ring shaped by internal hammering.

Alloyed Piston Rings

He was interested in the inclusion of alloy constituents such as molybdenum, in connection with which he had carried out a number of tests, but somewhat erratic results as regards "heat resistance" had been obtained with molybdenum cast irons. There would probably be general agreement with Mr. Geisler's remarks concerning piston ring wear, although this was not by any means so serious a problem as that of cylinder wear. In regard to the amount of surface, over which piston rings travelled, it might be stated, generally, that piston ring wear was exceedingly small in relation to the cylinder wear.

Reference had been made to the possibility of improving piston ring cast iron by heat-treatment, but there did not appear to be any reference to hardening and tempering in the Paper. Some interesting results had been obtained with hardened and tempered rings of $12\frac{3}{4}$ in. diameter which had been run in a Diesel engine with ordinary cylinder liner material. The results on both piston ring wear and cylinder wear were exceptionally good.

Author's Reply

Mr. Geisler, in replying to the discussion, first wished to convey to the membership of the Institute of British Foundrymen the greetings of the Verein Deutscher Eisengiesserein Giessereiverband, who extended to the members of the Institute of British Foundrymen an invitation to participate in conventions in Germany. An international congress was scheduled for next year to be held in September. English and German war veterans were now meeting together in fraternal intercourse at the prompting of the Prince of Wales, and therefore it might be regarded as quite a fitting thing for both English and German foundrymen periodically to foregather.

Case of Small Rings

He agreed with Mr. Twigger that narrow piston rings with an area of 2 m.m. thickness were easier cast centrifugally. In casting such

small rings in single castings, a large quantity of iron was required, the gates and runners amounting to approximately 85 per cent., while there was only altogether about 5 per cent. for the piston rings. Furthermore, very little castings were easily made hard and had to be machined afterwards. For large rings of 40 to 50 m.m. individual casting could be adopted. If single-cast piston rings were put into Diesel engines or aircraft engines they did not stand up well to wear. It was necessary to add alloys such as chromium, etc. Small rings up to 3 or 4 m.m. sq. were difficult to alloy. Chromium and molybdenum were used to make the iron very hard, and in the case of single-cast piston rings they were difficult to machine. They had not much experience of heat-treated piston rings in Germany. It was only recently that hardened piston rings had been tried but with very good results, however.

Heat-Shaping of Rings

It had been found that the heat-shaping of rings gave good results. With regard to piston-ring wear, of course, the liner wear was most important. It was found that with aircraft duties or with Diesel engines wear occurred in the piston rings.

He had considered it advisable to mention the work done in Germany for a number of years with respect to brake bands. Combined steel and cast iron was more usual than merely cast-iron work referred to by Mr. Twigger, because of the fact that the combined brake was much lighter in weight and much safer. The revolving brake was quite efficient for slow cars and large lorries, but for pleasure cars invariably the steel-cast iron composite brake had been found to be more efficient in Germany.

Mr. G. Williams, as the representative of a firm manufacturing centrifugal castings, confirmed Mr. Geisler's statement that centrifugal castings in the case of piston rings for high-duty engines were definitely superior to single cast rings.

Mr. J. A. Reynolds felt that the opportunity should not be allowed to pass of responding to

Mr. Geisler's invitation extended on behalf of the German Foundrymen's Society. He thought that the Institute should respond officially to the very welcome invitation which had been extended to them by their German colleagues.

Radial Pressure Determination

The PRESIDENT said he could add very little to what Mr. Twigger had said respecting piston rings because that gentleman's experience was so much greater than his own. Nevertheless, he had been concerned practically all his working life with the manufacture of centrifugal castings, the actual manufacture of piston rings having been the concern of others. This was, probably, the first occasion on which any British technical society had had placed before it some of the methods adopted by piston-ring manufacturers in the examination of piston rings. Figs. 6, 7 and 8 showed the actual results of the examination of piston rings for radial pressure, and gave some idea of the extent and the details of the methods adopted in carrying out investigations into the service value of such materials. As far as he was aware similar diagrams had not been published before in this country, though very extensive investigations had been published by a Japanese research worker, Mr. K. Ebihara, of Tokio. If that gentleman's very extensive publication was consulted, full details would be found of the types of machines used for studying the variation in radial wall pressure round the circumference of piston rings. Mr. Shaw had several time commented, in a somewhat cynical manner, on these tiny piston rings, but they were, nevertheless, a problem of very great interest to ironfounders in general. Even centrifugal castings and drum castings could be cut up into small rings. Perhaps one small drum casting having an average weight of something of the order of 7 lbs. was cut up into 20 or 30 rings, the user of those rings expecting each and every twentieth part of that casting to have absolutely identical physical and mechanical properties. It had been a long weary process to arrive

at a stage of production which satisfied the modern piston-ring maker and motor-car engineer. Mr. Shaw could well remember during the war period the difficulties experienced by the War Department in obtaining uniformity of properties of piston rings. It had taken a long time to reach the state of perfection which had been obtained already. It was only by intensive methods of investigation that that success had been achieved. He hoped that Mr. Geisler would receive much more discussion of his Paper by correspondence.

Vote of Thanks

Mr. F. J. Cook proposed a cordial vote of thanks to Mr. Geisler for his valuable Paper. Personally, he had received a great deal of consideration and pleasure when visiting Germany, and he hoped that Mr. Geisler would receive equal consideration and derive equal pleasure from his visit to this country.

The vote of thanks was seconded by the President and carried unanimously.

Mr. Geisler, in briefly responding to the vote of thanks, thanked the Institute of British Foundrymen for their invitation to attend their annual Conference, and for the kindness which had been extended to him during his visit to Sheffield.

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RELATIONSHIPS IN CAST-IRON TEST RESULTS

By G. L. Harbach (Member)

Introduction

The suggestion that cast iron is unreliable is to some extent justified when compared with a simple material like steel as, owing to the number of variable factors which operate in the production of iron castings, it is difficult to duplicate results exactly. However, if the extent of the variations can be determined, the

TABLE I.—*Typical Breaking Loads and Relative Sizes, etc., of Three Standard Test-Bars with Extra W.S. and 2-in. by 1-in. Bars for Comparison.*

	TRANSVERSE				TENSILE		
BAR	DIAM INS	SPAN INS	SPAN / DIAM	TYPICAL BREAKING LOADS LBS.	DIAM INS	AREA SQ INS	PROPORTION OF ORIGINAL BAR %
S	0·875	12	13·7	1360	0·564	·25	41·7
M	1·2	18	15·0	2310	0·798	·5	44·4
L	2·2	18	8·2	11,770	1·785	2·5	66·0
W-S	1·658	24	14·5	4020	1·13	1·0	46·7
2"×1"	–	36	–	3670	–	–	

resulting knowledge narrows the uncertainty to a known range; confidence on the part of designers is promoted and the large safety factors, generally considered necessary when using cast iron, may be modified.

There are a number of popular ideas regarding cast iron leading to the idea of unreliability which it was felt justified examination first to find if they were true and, if so, to what extent they operated in the mixtures under the author's control. Several investigations have been carried out on these and other points, mainly in the direction of establishing relationships, with a view to finding out the nature of any variables.

The most hopeful investigator of cast iron will admit the work is difficult. The attainment of reliable results under working conditions in any direction, is always liable to be disturbed by the introduction of some unexpected factor, apart

LE II.—*Factors to Calculate Transverse Breaking Load at Correct Size and Modulus of Rupture, from the Breaking Load of Bars of Various Diameters.*

$$\text{Corrected breaking load} = \frac{\text{actual breaking load} \times \text{standard diameter}^3}{\text{actual diameter}^3}$$

$$\text{Modulus of rupture in tons per sq. in.} = \frac{\text{Load in lbs.} \times \text{span in in.}}{4 \times \text{dia.}^3 \times 0.0982 \times 2240}$$

S Bar			M Bar.			L Bar.		
AM	Breaking Load to Load at '875" D.	Breaking Load to Modulus of Rupture	Diam.	Breaking Load to Load at 1·2" D.	Breaking Load to Modulus of Rupture.	Diam.	Breaking Load to Load at 2·2" D.	Breaking Load to Modulus of Rupture.
77	1·469	·02990	1·10	1·298	·01521	2·10	1·150	·002210
78	1·413	·02878	1·11	1·264	·01491	2·11	1·134	·002180
79	1·358	·02765	1·12	1·230	·01462	2·12	1·117	·002150
80	1·308	·02663	1·13	1·198	·01413	2·13	1·103	·002115
81	1·261	·02568	1·14	1·166	·01376	2·14	1·087	·002090
82	1·216	·02477	1·15	1·136	·01341	2·15	1·071	·002060
83	1·172	·02386	1·16	1·107	·01307	2·16	1·056	·002030
84	1·130	·02300	1·17	1·079	·01274	2·17	1·041	·002000
85	1·091	·02220	1·18	1·052	·01242	2·18	1·027	·001975
86	1·053	·02143	1·19	1·025	·01210	2·19	1·014	·001945
87	1·018	·02072	1·20	1·000	·01180	2·20	1·000	·001922
875	1·000	·02036	1·21	·976.	·01161	2·21	·987	·001895
88	·984	·02003	1·22	·952	·01124	2·22	·974	·001870
89	·951	·01935	1·23	·930	·01096	2·23	·961	·001845
90	·920	·01871	1·24	·906	·01068	2·24	·947	·001818
91	·889	·01809	1·25	·884	·01043	2·25	·935	·001796
92	·861	·01751	1·26	·864	·01019	2·26	·924	·001773
93	·834	·01696	1·27	·845	·00997	2·27	·912	·001750
94	·808	·01643	1·28	·826	·00973	2·28	·900	·001727
95	·782	·01592	1·29	·806	·00950	2·29	·888	·001703
96	·758	·01541	1·30	·787.	·00928.	2·30	·876.	·001681
97	·734.	·01494						

EXAMPLE:- BREAKING LOAD OF 2570 LBS. WITH 1·22" DIAM.
2570 × ·952 = 2445 LBS. ON 1·2" DIAM.
2445 × ·0118 = 28·9 TONS PER SQ. IN. MODULUS OF RUPTURE.
OR 2570 × ·01124 = 28·9 " " " " " " "

from the inevitable variations in the material. It is for this reason that all conclusions are based on the average of all the results available in any one series, the number of tests being quoted in most cases. Furthermore, to reduce

variables, all the bars dealt with were cast on end in green sand except the high-test irons which were mainly cast in dry sand. They were made by drawing the pattern out full length, thus avoiding the interference of a joint and providing bars practically true to shape. Unless stated otherwise, the only treatment was lightly grinding on a fettler's grinding wheel in the usual manner.

TABLE III.—*Effect of Machining Transverse Bars.*

Nº OF BARS	DIAM INS.		TENSILE	MODULUS OF RUPTURE TONS □"		GAIN %		
	CAST	MACHINED	TONS □"	AS CAST	MACHINED	MEAN	HIGH	LOW
3	0·88	0·8	15·1	28·3	30·9	9	18	4
1	0·88	0·8	20 APPROX	28·4	36·1	27	-	-
3	1·2	1·1	14·7	26·1	28·8	10·5	11	10
3	1·2	1·1	21·1	34·4	40·2	17	28	9
3	1·2	0·9	14·7	26·1	29·5	13	20	7
1	1·65	1·6	17 APPROX	24·1	29·3	21	-	-
3	1·65	1·5	14 "	23·6	28·2	19	30	16
3	1·65	1·3	14 "	23·6	28·3	20	31	13
1	1·65	1·5	18 "	28·6	35·8	25	-	-
1	1·65	1·4	18 "	29·8	36·6	23	-	-
1	1·65	1·3	18 "	28·6	34·3	20	-	-
2	1·65	1·2	18 "	30·0	35·8	19	18	21
1	1·65	1·0	18 "	30·1	32·8	9	-	-

SPANS USED IN ABOVE TESTS

DIAM	AS CAST	MACHINED
0·88"	12"	12"
1·2"	18"	12"
1·65"	24"	12"

Effect of Incorrect Size on Transverse Breaking Load

The most common test applied to cast iron is the transverse test. Being cheap, simple and speedy, it is favoured for routine testing. It may be carried out to give, apart from transverse strength and deflection, valuable information on the properties of toughness, elasticity and resilience as shown by Pearce.[1]

Up to 1928 the standard test-bars were either 2 in. by 1 in. by 36 in. or 1 in. by 1 in. by 12 in. Specifications called for a minimum breaking

load and occasionally minimum tensile strengths according to the wishes of the purchaser or inspector. The now familiar three round bars were then adopted and the B.S.I. Specification issued covering two grades of iron with minimum transverse and tensile strengths. Prior to this, the author, whilst experimenting with mixtures for high-duty work, found it necessary to use round test-bars to avoid the chill which invariably occurred in the (then) standard rectangular bars. The size finally selected was 1.655 in. dia. ($1\frac{5}{8}$ in. for practical purposes) broken at a span of 24 in., which should theoretically break at the same loads as the 2 in. by 1 in. by 36 in. bar, thus giving results in terms familiar to all concerned—a point of importance in the foundry where, as a rule, strength was (and often still is) considered in terms of the 2 in. by 1 in. bar.

The $1\frac{5}{8}$ in. dia. bar is still used as it has its scope of usefulness, being almost midway between the M and L bars of the standard specification, but what is likely to be more important, if the E value is included in cast-iron specifications, the span/diameter ratio is practically identical with the S and M bars of the specification and also a suitable tensile bar contains almost the same proportion of the original bar, neither of which can be said of the standard L bar. Table I shows the relative sizes, etc., of the four bars, and it is suggested that when the cast-iron specification[2] be revised the extra bar might be considered as a useful addition to the series.

Whilst the foundryman uses the transverse test as a routine test, the engineer as a rule prefers to consider tensile strength as a basis for design. If a ratio between transverse and tensile strength can be established, it would enable both foundrymen and engineers cheaply and readily to obtain the results most suitable for their respective purposes. Such a relationship requires that both properties be in the same terms—generally tons per sq. in. This is usual for tensile, but the breaking load in transverse requires converting to modulus of rupture by a formula, which takes into consideration the

shape, size and span of the test-bar. For this purpose, it is essential that the bar be measured accurately, as the slight, but inevitable, variations in size, even when using the same pattern, will cause comparatively wide differences in breaking load. When the 2-in. by 1-in. bar was used, it was usual to allow 1 cwt. per $\frac{1}{32}$ in., which was fairly close for small differences when the breaking load was from 30 to 35 cwts. Using

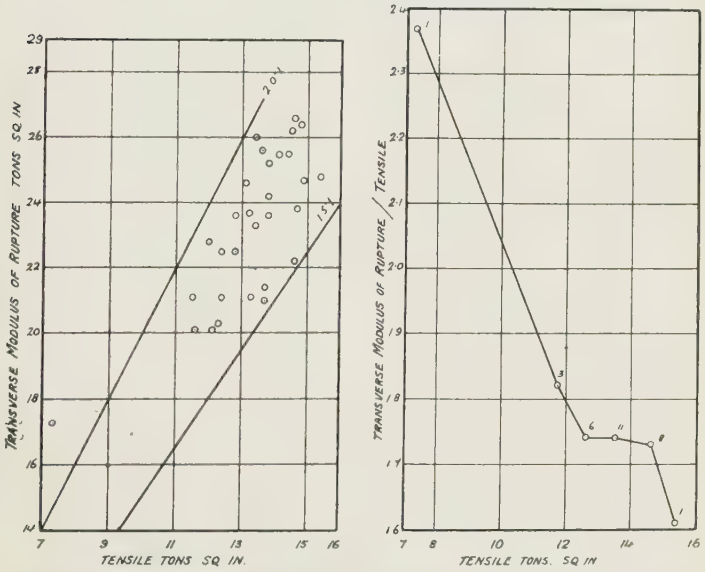

FIG. 1.—TRANSVERSE, TENSILE RESULTS AND RATIOS, 2-IN. × 1-IN. BARS.

the M bars for Grade A iron, 0.025 in. will affect the breaking load about 100 lbs., or 1.2 tons modulus of rupture (5 per cent. error), and with an iron of 16 tons tensile about 160 lbs., or 1.8 tons (6 per cent. error), so that for routine testing, when using the same size of bar for comparing different mixtures, the corrected breaking load is necessary, and the modulus of rupture must be determined to compare the

results of bars of different shapes. The B.C.I.R.A. recommendation (see Pearce[3]) that modulus of rupture be used for reporting transverse strength is strongly supported, and this method is used by the author.

It is an advantage to have a chart with the correction factors for most of the variations of standard bars, and this is given in Table II, together with the formula and factors for calculating the modulus of rupture. Columns 2,

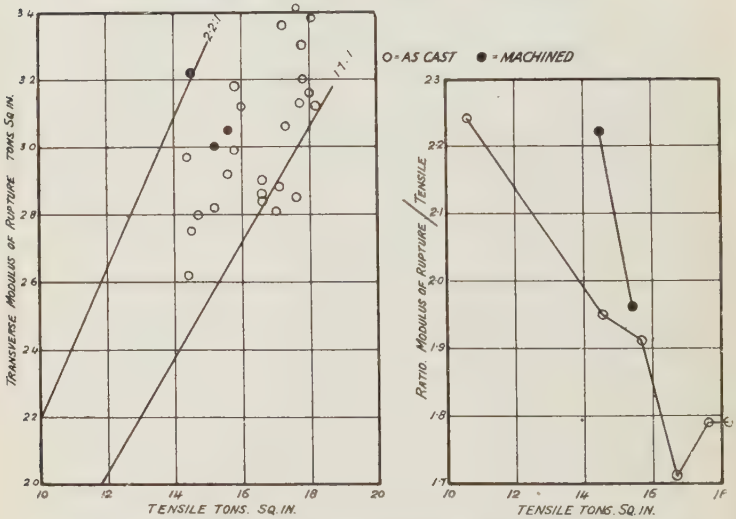
TRANSVERSE MODULUS OF RUPTURE TONS SQ IN.
TENSILE TONS. SQ.IN.
2·2:1
1·1:1
O = AS CAST ● = MACHINED
RATIO MODULUS OF RUPTURE / TENSILE
TENSILE TONS. SQ.IN.

FIG. 2.—TRANSVERSE, TENSILE RESULTS AND RATIOS, 0.875-IN. DIA. BARS.

5 and 8 give the factors for calculating breaking load to correct size, and columns 3, 6 and 9 the factors for calculating modulus of rupture direct from the breaking load of bars of incorrect sizes.

Relation Between Transverse and Tensile Strengths

Figs. 1 to 4 show transverse and tensile results of 2 in. by 1 in., and three round bars from ordinary foundry mixtures (the results of

L bars being too few to be representative have been omitted), and the ratio curves obtained by dividing the transverse by the tensile strength for each sample and taking the mean in groups of each ton of tensile strength. Figs. 5 and 6 give the same information regarding high-test cast irons, one the low-carbon type (2.6 to 2.8 per cent. T.C.) without alloys, and the other a medium-carbon (2.9 to 3.1 T.C.) type containing $1\frac{1}{2}$ per cent. nickel.

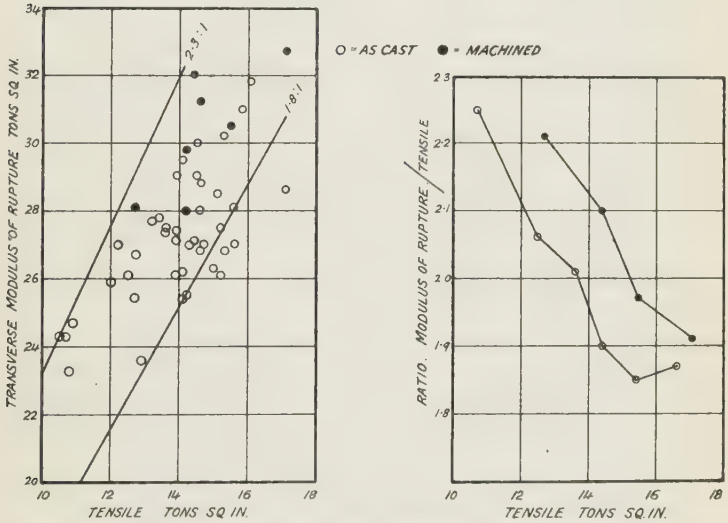
TRANSVERSE MODULUS OF RUPTURE TONS SQ IN.
TENSILE TONS SQ IN.
2·3 : 1
1·8 : 1
O = AS CAST
● = MACHINED
RATIO. MODULUS OF RUPTURE / TENSILE
TENSILE TONS SQ IN.

FIG. 3.—TRANSVERSE, TENSILE RESULTS AND RATIOS, 1.2-IN. DIA. BARS.

It will be seen that the trend in every case is for the ratio to fall as the strength increases. In other words, tensile strength increases proportionally more rapidly than transverse strength. In the 2-in. by 1-in. bars the ratios fall between 2 and 1.5, with a fairly close average around 1.8 to 1.7 except for the 7.2 tons tensile sample, which is included to show the type of relationship existing in the low-strength irons. Further, in connection with 2-in. by 1-in. bars,

12 results from bars cast under different conditions, having a tensile range of 11 to 14 tons, gave ratios of 1.7 to 1.4, the average being 1.67 to 1.5. These results are mentioned as being similar to those occasionally used for calculating, but are definitely below the results shown in Fig. 1, and still more below the results from round bars, a case in point being the standard formula for piston-ring tests (1.6).

Examination of Figs. 2, 3 and 4 shows that

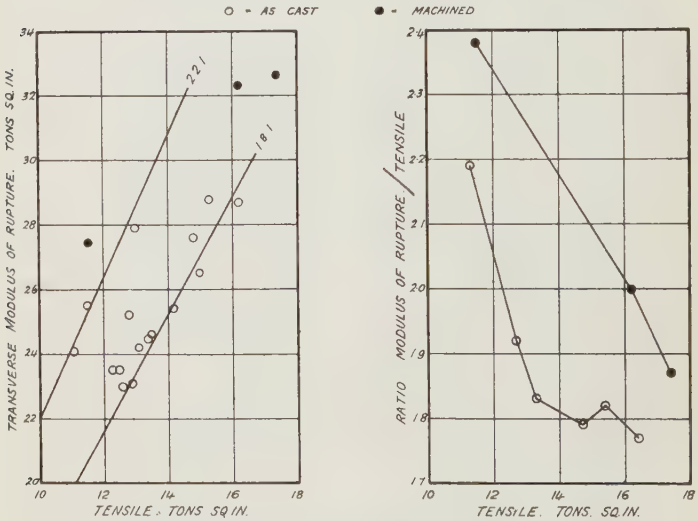

FIG. 4.—TRANSVERSE, TENSILE RESULTS AND RATIOS, 1.65-IN. DIA. BARS.

there is little difference between the ratios of the three bars for the results under review, although calculations made from the Institute of British Foundrymen's Sub-Committee's Report[4] clearly showed a marked difference in ratios between the S, M and L bars over tensile ranges of 11 to 18 tons. These were very close to 1.9 throughout for the L bar; from 2.4 to 2 for the M bar—much higher than shown in Fig. 3—and from 1.8 to 1.5 for the S bar which is rather lower

than is shown in Fig. 2. Consideration of these differences supports the view that irons produced under uniform conditions are less affected in their properties by variations in section size than irons produced under varying conditions when it is remembered that the Institute's experiments were carried out on 40 different irons with deliberate variations of analysis.

If the ratio curves be examined without considering the results from which they were compiled, they indicate closer relationships than actually occur in practice, and each has been included in the same figure to permit easy comparison of the variations above and below the mean. The fact that all are taken from commercial results obtained from different cupolas, various mixtures, etc., without discrimination, increases the width of variation as compared with a few results prepared under carefully controlled conditions, but from a practical point of view this should be more advantageous than otherwise. In the majority of cases a range of 1 ton tensile is associated with a range of 2 to 4 tons transverse and a range of 1 ton transverse with a range of 2 to 3 tons tensile, thus calculations from the mean ratios can only be accepted within ± 8 per cent. when taking the curves as a whole. Experience has shown, however, that for a constant mixture the limits for tensile may be considerably reduced. As an instance the group of nine results from the S bar ranging between 17.3 and 18.3 tons tensile and 30.5 to 34.2 tons transverse were all from the same mixture taken over a period of several months. The limits about the mean being ± 3 per cent. in tensile and ± 6 per cent. in transverse suggests that under standardised conditions the tensile is less variable than the transverse. Such a result is not unexpected as it is well known that slight defects in the surface of a transverse bar on the tension side may cause a considerable drop in breaking load, although the fracture may appear sound—a loss of strength which does not occur in the tensile bar as it is invariably machined. The

effect of different surface finishes on the transverse result will be dealt with later, but at present it will be well to note the higher average strength of the machined bars.

In the low-carbon iron (Fig. 5) the results and ratios are scattered more widely than those of the irons of lower strength. In the tensile range 21 to 22 tons the transverse varies from 32 to 42 tons (ratios 2 : 1 to 1.5 : 1) for the as-cast bars, and although the machined bars are in the main more consistent (ratios 2.2 : 1 to 1.9 : 1) —and show more marked increases in transverse strength than machined bars of lower-strength irons—two machined bars (21.8 and 24.2 tons tensile) are well below the mean of the series. This suggests that for this class of iron machined bars are to be recommended if reliable transverse results are to be obtained, although factors causing high tensile strength may not necessarily raise the transverse to the same degree, even when machined bars are used, as shown by the two bars mentioned. Incidentally, the A.S.T.M. specification for two irons with minimum tensile strength of 22.3 and 26.8 tons show ratios of 1.48 and 1.37 respectively for the 1.2-in. dia. bar which appears to be a generous allowance for low transverse results in this class of iron, although for the 0.875 in. and 2 in. dia. bars the ratios for the same tensiles are 1.55 and 1.58, and 1.68 and 1.65 respectively.

Fig. 6 shows 1½ per cent. nickel irons intended to meet a specification of 18 to 20 tons tensile of the 1.2 in. dia. bars with the exception of the 23 to 24 ton results which were from an experiment to produce a 25-ton iron by inoculation. Compared with Fig. 5 the lower tensile strength gives the impression of better grouping and greater consistency which may not be quite justified, but on the practical side there is no doubt that when high strength is a primary consideration the inclusion of 1½ per cent. nickel not only produces more consistent results but, by permitting a higher total carbon, considerably improves the castability, and on this account may more than offset the increase in metal cost by reduced scrap castings.

Dealing with Figs. 5 and 6 together, the mean ratios commence roughly where the lower strength irons left off—1.8 at 16 tons—falling to 1.6 for 20 to 28 tons, which is quite close to the A.S.T.M. ratios for the 0.785-in. and 2-in. dia. bars previously mentioned. In this respect it is worthy of remark that the Institute's results, the A.S.T.M. specification and the author's results for the largest bar all vary over a narrower

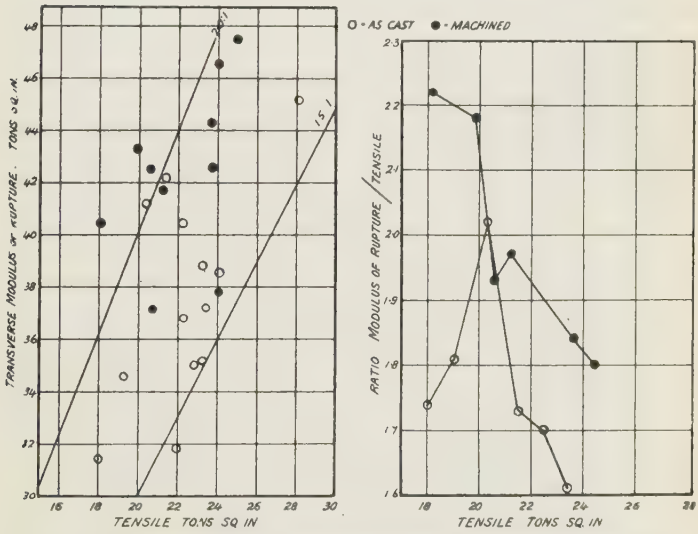
TRANSVERSE MODULUS OF RUPTURE. TONS SQ. IN.
TENSILE TONS SQ IN
O - AS CAST ● - MACHINED
RATIO MODULUS OF RUPTURE / TENSILE
TENSILE TONS SQ IN

Fig. 5.—Transverse, Tensile Results and Ratios, High-Test Cast Iron (Low Carbon), 1.2-in. dia. Bars.

range of ratios than either of the other two bars.

Fig. 7 gives the combined ratio curves from Figs. 2 to 6, from which it may be noted that the ratio of 2 to 1.8 for 13 to 17 tons tensile confirm the results of Pearce[5], and, on the whole, follow similar lines to the five curves quoted by MacKenzie,[6] except for the sharp fall from 1.6 to 1.1 for strengths of 17 to 26 tons. Whilst in the irons below 18 tons tensile the transverse

strength may be considered as having a fairly close relationship, it is obvious that, with the stronger irons, the relationship varies more widely, even with machined transverse bars, so that tensile tests are necessary if the actual strength is to be determined.

Summarising the conclusions regarding transverse and tensile relationship: The ratio falls with increasing strength from 2.3 at 10 tons tensile to 1.6 or less at over 20 tons tensile, but is not constant for any particular range of strength

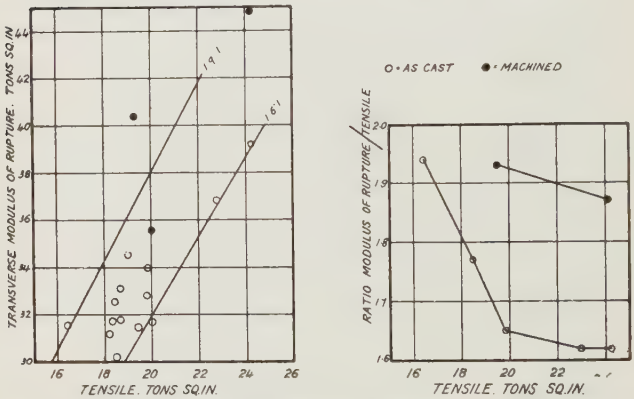

FIG. 6.—TRANSVERSE, TENSILE RESULTS AND RATIOS. HIGH-TEST CAST IRON (1.5 PER CENT. NICKEL), 1.2-IN. DIA. AND 1.65-IN. DIA. BARS.

within closer limits than ± 8 per cent., except when produced under closely-controlled conditions, when, from a mixture of pre-determined strength, a normal transverse result will generally indicate a normal tensile strength. Machined transverse bars are higher in strength than bars tested "as-cast," thus giving higher ratios—a difference which increases with increasing strength.

On the whole, it is felt that for irons in which strength is an important feature the transverse test is a useful guide for routine tests, but for

all other purposes the determination of tensile strength is preferable to estimation from transverse strength, particularly as engineers think of strength in terms of tensile, and therefore by this method will more readily appreciate the improved properties of cast iron and the high strengths now available. Moreover, tensile will probably prove the more suitable means of classification when the high-strength irons are included in a standard specification.

Effect of Surface Condition on the Transverse Result

It is well known that the breaking load of a test-piece is affected by the surface finish, but against this, so far as cast iron is concerned, it is popularly believed that the skin is the strongest part of a bar, although usually in such a case the surface is bound to be rough. Transverse tests were carried out to find the difference between bars:—

(*a*) As removed from the mould and adhering sand removed by a wire brush.

(*b*) Fettled in the normal manner by lightly grinding so that all sand and roughness were removed, but in the main with the skin left intact.

(*c*) By grinding more than usual to remove the skin entirely (actually 0.01 to 0.02 in.).

(*d*) By machining to various depths.

With the exception of the machined bars, pairs of bars were cast in each case, one being treated normally (*b*) and the other having the special treatment (*a*) or (*c*). The following summarises the results obtained in tons per square inch modulus of rupture:—

Mean of 12 bars treated normally (*b*)	23.6
Mean of 12 bars with skin untouched (*a*)	22.8
Mean loss by no grinding	0.8
Highest loss by no grinding ...	2.4
Lowest loss by no grinding (gained)	0.7

Apart from the highest and lowest differences, the losses consistently varied between 0.3 and

1 ton, so that if the high and low were discarded as being due to other causes, the mean would still remain the same.

Mean of 8 bars treated normally	(*b*)	26.8
Mean of 8 bars skin ground	(*c*) ...	26.05
Mean loss by skin grinding	...	0.75
Highest loss by skin grinding	...	1.3
Lowest loss by skin grinding	...	0.3

Owing to the consistency of these results, eight bars were considered as sufficient to prove the point.

The mean differences, which amount to about 3 per cent. in each case, are no more than might be expected between any pair of bars, but the trend is sufficiently marked as to be definitely against either no grinding or severe grinding, although in the latter case, if the grinding wheel was wearing smooth, something approaching a machined finish might be obtained to the advantage of the bar. Table III gives the results of different sizes of bars from high- and medium-strength mixtures tested "as-cast" (normal fettling), and after machining to various diameters. The S bars were from duplicates, one as-cast and one machined; the M bars were from top and bottom halves of 26-in. bars machined and tested at 12 in., previously tested "as-cast" at 18 in.; and the 1⅝-in. bars were from top and bottom halves of 26-in. bars machined and tested at 12 in., previously tested "as-cast" at 24 in. The difference due to shorter span would be much less than the increases shown, and does not affect direct comparisons between the same size bars from different mixtures.

The largest mean increase is associated in each case, for the same machining, with the higher-strength iron—which confirms the curves of Fig. 7—although in some individual bars of medium strength iron gains of up to 31 per cent. occur. In no case, even when machined from 1.65-in. dia. to 1.3-in. dia. in a 14-ton iron or to 1-in. dia. in the 18-ton iron, did the results from the machined bar fail to exceed the result of the bar tested "as-cast."

No further results are available in this series, but they are sufficient to show that machining of high-strength bars is to be recommended if the real strength is to be determined, and in the event of an oversize bar having to be machined to comply with specification, no reduction of modulus of rupture is to be expected, although, of course, the breaking load will be lowered.

Relation between Tops and Bottoms of Bars

It is generally accepted that the bottom of a bar cast on end is stronger than the top and that modulus of rupture increases with decreasing span. These two factors were considered to-

TABLE IV.—*Average Results of* 13 2-*in. by* 1-*in. by* 40-*in. Bars, Cast from the Same Mixture and Tested at* 36-*in. and* 12-*in. Spans.*

	TRANSVERSE MODULUS OF RUPTURE.					
	MIDDLE AT 36"		TOP HALVES AT 12"		BOTTOM HALVES AT 12"	
	TONS □"	%	TONS □"	% OF 36" MEAN	TONS □"	% OF 36" MEAN
MEAN	21·5	100	22·7	105·5	22·3	106·5
HIGH	23·7	110·5	26·8	124·5	26·6	124·0
LOW	20·4	96·0	20·0	93·0	20·1	93·5
	DEFLECTION.					
	INS	%	INS.	% OF 36" MEAN	INS.	% OF 36" MEAN
MEAN	0·404	100	0·111	27·6	0·125	31·0
HIGH	0·452	112	0·121	30·0	0·137	34·0
LOW.	0·332	82·5	0·091	22·6	0·094	23·3.

gether, and the conclusions drawn from the same series of tests. The results are given in Tables IV, V and VI.

Comparing the results obtained from top and bottom halves of bars the latter are slightly higher in average strength but in no instance is the gain consistent. Individual bars gave results differing as much as 10 per cent., the higher strength not always being from the bottom half. Table V gives the results of two series of 14 bars each, one of which showed no difference in strength between tops and bottoms and the other showed the bottoms to be strongest by 1 ton. This is representative of the results

generally obtained and leads to the conclusion that there is little difference in strength as a rule, but when there is a difference it is generally in the direction of higher strength in the bottom of the bar.

Tensile strength has not been considered so thoroughly as transverse, but it may be mentioned that out of six bars from an iron consistently close to 14 tons tensile, five did not vary more than 0.3 ton and the sixth gave 13.9 and 15.0 tons from top and bottom respectively. This appears to confirm the conclusion reached with

TABLE V.—*Average Results of Two Sets of* 14 *Specimens,* 26-*in. by* 1.2-*in. Dia. Bars, Cast from the Same Mixture and Tested at* 18-*in. and* 12-*in. Spans.*

	TRANSVERSE MODULUS OF RUPTURE					
	MIDDLE AT 18"		TOP HALVES AT 12"		BOTTOM HALVES AT 12"	
	TONS ☐"	%	TONS ☐"	% OF 18" MEAN	TONS ☐"	% OF 18" MEAN
FIRST SET.	26·0	–	26·5	–	27·5	–
SECOND SET	25·7	–	25·9	–	25·9	–
MEAN	25·8	100	26·2	101·5	26·7	103·5
HIGH	28·5	110·5	29·1	113	30·2	117
LOW.	24·3	94	23·0	89	24·7	96
	DEFLECTION.					
	INS	%	INS.	% OF 18" MEAN	INS	% OF 18" MEAN.
FIRST SET.	0·201	–	0·121	–	0·125	–
SECOND SET	0·194	–	0·125	–	0·121	–
MEAN	0·198	100	0·123	62	0·123	62
HIGH	0·228	115	0·137	69	0·145	73
LOW.	0·172	87	0·108	54·5	0·109	55

regard to transverse, although the result of 15 tons is so high for that particular iron that it might be considered a freak.

To check further the effect of length of bar on strength, the top and bottom of a runner 9 ft. long and $2\frac{1}{4}$ in. dia. were tested at 30 in. span as cast, and the broken halves used for further tests. The extreme top and bottom ends were machined to 1.5 in. dia. for testing in transverse at 12 in. span and the other halves for tensile tests on 1.595 in. dia. The results obtained are given on page 333.

	Top.	Bottom.
		Tons per sq. in.
Transverse as-cast 2¼ in. dia., 30-in. span	23.0	23.7
Transverse machined to 1.5 in. dia., 12-in. span	24.5	21.8
Tensile 1.595 in. dia.	12.1	10.9
Brinell hardness Nos.	207	187

The " as-cast " result is doubtful as the sand had burnt on about ⅛ in. thick on the bottom bar and was considered as having no strength when the modulus of rupture was calculated—an allowance which the other results suggest was too generous. All three fractures of the bottom bars were more open than the top fractures. It is not suggested that these results are directly comparable with those of test-bars, owing to the difference in casting and cooling conditions, but they are the most extreme examples available of bottom in relation to top, and are included as a matter of interest chiefly because the results were contrary to expectations.

Effect of Span on Modulus of Rupture

In Table VI the results from three mixtures are shown so that high and low strength and percentage variations from the mean are no guide to the consistency of the mixture, but in Tables IV and V both sets of results were from the same mixture—although cast at different periods—so that, apart from the factors under review, they serve to show the relation between 2 in. by 1 in. and 1.2 in. dia. bars. Under the standard conditions of testing, both series show variations from 10 per cent. above to 5 per cent. below the mean, and the results of the short bars show wider variations, so, although there is a definite increase in average strength when the span is shortened, it is not consistent, and, in fact, occasionally the shorter bar is the weaker of the two. This is most marked in Table VI, which shows that the lowest results for top and bottom halves at 12-in. span are 1.6 and 0.4 tons

below the lowest for the 24-in. span and the highest result was obtained from a 24-in. bar.

The following summarises the conclusions from Tables IV, V and VI:—

Bar.	Decreasing span		Strength altered. Per cent.			Deflection decreased. Per cent.
	From	To	Mean.	High.	Low.	
	in.	in.				approx.
2 by 1 in.	36	12	+6	+14	−2	72
1.2 in. dia.	24	12	+4	—	—	65
1.2 in. dia.	18	12	+2·5	+7	−5	38

Reviewing the results as a whole, it may be accepted that for any series of tests the average results are highest when the span is shortest and the greater the difference in span the greater the difference in strength, but the relationship is not sufficiently consistent to apply it with accuracy to any particular bar, although, if the limits are appreciated, it may be of use as shown below.

Dealing with the 1.2-in. dia. bars shown in Table V, as the most likely to be of practical importance, the results from 12-in. bars may be expected to be about 0.8 ton higher than the results from 18-in. bars, with the possibility that the difference may be ± 1.5 tons. Actually, the differences in individual bars were slightly wider as the high and low results, at 18 in. were not always from the same bars which gave the high and low results at 12 in., but invariably the average from each pair of bars fell within the limits shown. (This remark also applies to the results in Tables IV and VI for their respective spans, and also the deflection results in each table.) Assuming a pair of 1.2-in. dia. bars cast 26 in. long gave variable results when tested at 18 in., either with or without apparent flaws to account for the difference, the testing of each half would yield four more results, which could be calculated within known limits to the results

at 18 in., thus allowing a more accurate conclusion to be drawn than would be possible from the first results. The factors required are 0.97 for the modulus of rupture and 1.6 for the deflection. Taking a pair of bars used in Table V, which gave the widest variation, as an illustration, the results were 26.9 and 24.8 tons at 18 in. (both being apparently sound), and 28.1, 27.4, 30.2 and 27.7 at 12 in. The mean at 12 in. was 28.35 tons, multiplied by 97, gave 27.4, which confirmed the higher of the two first results.

TABLE VI.—*Average Results of* 14 *Specimens of* 26-*in. by* 1.2-*in. Dia. Bars Cast from Three Different Mixtures and Tested at* 24-*in. and* 12-*in. Spans.*

	TRANSVERSE MODULUS OF RUPTURE							
	MIDDLE AT 24"		MIDDLE AT 12"		TOP HALVES AT 12"		BOTTOM HALVES AT 12"	
	TONS □"	%	TONS □"	% OF 24" MEAN	TONS □"	% OF 24" MEAN	TONS □"	% OF 24" MEAN
MEAN	26·3	100	27·3	103·7	27·3	103·7	27·4	104·1
HIGH	32·0	121·5	29·7	113	29·2	111	31·0	118
LOW	24·3	92·5	25·0	95	22·7	86·5	23·9	91
	DEFLECTION.							
	INS	%	INS	% OF 24" MEAN	INS	% OF 24" MEAN	INS	% OF 24" MEAN
MEAN	0·341	100	0·114	33·5	0·122	35·8	0·119	35
HIGH	0·395	116	0·140	41	0·140	41	0·133	39
LOW	0·293	86	0·098	28·7	0·100	29·4	0·107	31·4

Examination of Table VI shows that for bars tested at 12 in., and each half again tested at 12 in., no difference in average strength occurred. This confirms the experience of Pearce[1] that "the material on either side of a transverse break can be used with safety for further tests without risk."

The deflection results given in Tables V and VI were all corrected for errors in bar size, but as the load varies as dia.^{4} and the deflection as dia.^{4} *in the opposite direction*, once the corrected load has been calculated, three-quarters of the error in deflection is adjusted, and the remaining error is rarely significant. Actually, it is approximately 0.0017 in. for 0.01-in. error

in dia. on the 1.2-in. dia. bar tested at 18 in. from the formula:—

$$\text{Corrected deflection} = \frac{\text{Actual deflection} \times \text{actual dia.}}{\text{Standard dia.}}$$

Relationship between Different Sizes of Test-Bars

This investigation was carried out to find in what way the strength of different sizes and

TABLE VII.—*Transverse Strength Relationship between Various Test-Bars. Mean Result of* 1.2 *Dia. Bar taken as* 100 *for each Group.*

Nº OF BARS	1·2" DIAM MEAN. TEN TONS	1·2" DIAM MEAN. M.R. TONS	0·875" DIA Nº OF BARS	0·875" DIA MEAN	1·655" DIA Nº OF BARS	1·655" DIA MEAN	2·2" DIA Nº OF BARS	2·2" DIA MEAN	2" × 1" Nº OF BARS	2" × 1" MEAN	1" × 1" Nº OF BARS	1" × 1" MEAN
1	9·3	22·7	1	105	-	-	1	82	-	-	-	-
7	12·7	25·8	5	112	6	92	-	-	3	83	1	105
3	13·7	28·3	1	104	1	93	1	86	2	87	1	86
7	14·3	27·3	5	109	7	91	1	93	4	84	1	86
4	15·3	28·8	3	107	3	92	2	89	2	85	1	84
2	16·2	31·5	2	103	-	-	2	84	-	-	-	-
3	17·7	29·2	3	109	3	93	1	96	1	91	-	-
4	18·6	33·2	3	103	3	95	-	-	-	-	-	-
4	19·5	33·7	3	106	2	92	2	84	-	-	-	-
2	22·1	38·6	2	98	2	94	-	-	-	-	-	-
MEAN			28	107	27	92	10	87	12	85	4	90
HIGH *			-	117	-	106	-	103	-	98	-	105
LOW *			-	96	-	80	-	82	-	71	-	84

* TAKEN FROM ORIGINAL BARS.

shapes of test-bars compared, and naturally links up with the effect of section size on strength. From two sets of curves in the Paper by Pearce[5] the broad conclusion might be drawn that strength decreases as the section increases, and the effect may or may not become more pronounced as the silicon rises (or strength falls), a variation which appeared to be dependent on factors apart from composition. With this in mind, it was decided to calculate the mean strength of different bars in groups of 1 ton tensile based on the strength of the 1.2-in. bar.

The results obtained are tabulated in Tables VII and VIII.

It will be noticed that the results of only four 1-in. by 1-in. bars were available for comparison. This was due to the fact that this size of bar has rarely been used since the round bars were adopted, and in consequence the ratios shown cannot be accepted with the same confidence as those obtained from larger numbers of bars. Tests to determine the relationship

TABLE VIII.—*Tensile Strength Relationship between various Test-Bars. Mean Result of* 1.2 *in. Dia. Bar taken as* 100 *for each Group.*

Nº OF BARS	1·2" DIAM. MEAN TENSILE TONS ☐"	·875" D.		1·655 D		2·2" D		2"x1"		1"x1"	
		Nº OF BARS	MEAN	Nº OF BARS	MEAN	Nº OF BARS	MEAN	Nº OF BARS	MEAN	Nº OF BARS	MEAN
1	9·3	1	114	-	-	1	88	-	-	-	-
7	12·7	3	114	2	90	-	-	1	90	1	97
3	13·7	2	117	1	92	1	86	1	105	1	86
7	14·3	3	109	4	90	1	91	4	91	1	98
4	15·3	1	108	1	98	1	83	2	91	1	94
2	16·2	2	111	-	-	2	93	-	-	-	-
3	17·7	-	-	-	-	-	-	-	-	-	-
4	18·6	-	-	1	93	-	-	-	-	-	-
4	19·5	1	94	1	94	-	-	1	87	-	-
2	22·1	2	101	2	94	-	-	-	-	-	-
MEAN		15	110	12	92	6	89	9	92	4	94
HIGH *		-	128	-	98	-	97	-	105	-	98
LOW *		-	94	-	87	-	83	-	86	-	86

* TAKEN FROM ORIGINAL BARS.

between 2-in. by 1-in. and 1-in. by 1-in. bars were carried out about 20 years ago by the late G. Hailstone,[7] who concluded the factor for transverse breaking loads was 1.15 instead of the theoretical 1.33, which showed the 1-in. by 1-in. bar to be relatively the stronger of the two. The results in Table VII support this, but are insufficient to establish a ratio.

When round bars were used, it was soon realised that in transverse strength they were relatively stronger than rectangular bars. Bach[8]

shows that variations also occur with other section shapes. Several workers have investigated the relation between 2-in. by 1-in. and 1.2-in. dia. bars. Again quoting from the same publication, the average ratio between 2-in. by 1-in. by 24-in. and 1.2-in. dia. for 39 sets of bars in triplicate is given as 0.84, and for other rectangular and round bars as 0.83, both being very close to the 0.85 shown in Table VII, and the results of Tables IV and V, which work out at

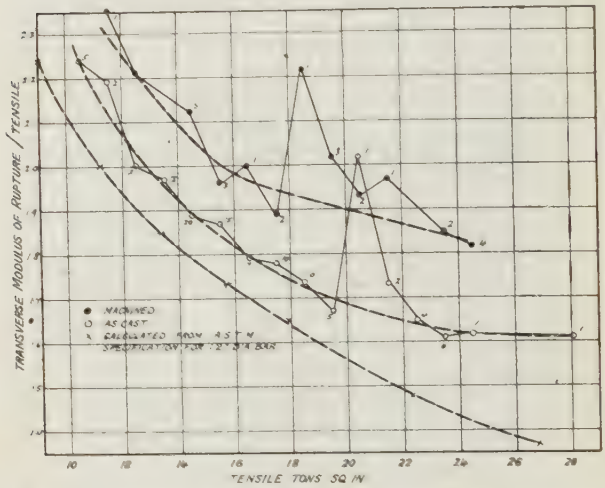

Fig. 7.—Transverse, Tensile Results and Ratios, Combined Curves.

0.834. It may therefore be accepted that the 1.2-in. dia. bar is approximately 20 per cent. stronger than the 2-in. by 1-in. bar in transverse strength, although individual results may vary up to 15 per cent. or more about the mean.

Considering the tensile strength, both the 2-in. by 1-in. and 1-in. by 1-in. bars show a higher ratio than for transverse—92 and 94, against 85 and 90 respectively—which again indicates the lowering effect of rectangular sections on transverse test results, and shows why the

curve of transverse/tensile ratios is lower for 2 in. by 1 in. than for round bars in Figs. 1 to 4. Whilst the 2-in. by 1-in. transverse strength is rather lower than the 2.2-in. dia. bars, the tensile is equal to the 1.65-in. dia. bar —an increase of about 8 per cent., making the ratio to the 1.2-in. dia. bar 0.92 instead of 0.85 as in transverse. If the 1.65-in. dia. by 24-in. bar is adopted with a view to giving the same breaking loads as 2 in. by 1 in. by 36 in., it would need to be reduced to 1.6-in. dia. This would not affect the close tensile results, and the span/diameter ratio would then be exactly the same as the 1.2-in. dia. bar.

Turning to the results of round bars, it was expected that, as the strength increased, the percentage difference in each size of bar compared with the 1.2-in. dia. bar would decrease, but, except in very low- and very high-strength irons, such an effect is not noticeable, and for practical purposes the mean of each series is applicable to all the usual grades under the conditions of manufacture and testing. There is a steady reduction in strength as the section is increased, and, apart from the 0.875-in. dia. bar, which seems to gain a little more in tensile than transverse by the smaller section, both strengths are reduced to the same extent. Factors, taking the 1.2-in. dia. bar as standard, are the mean results divided by 100.

Effect of Section Size on Strength

The fact that cast iron is lowered in strength by increasing section is well known and may, by undue emphasis, be used to its detriment, but it is often overlooked that the same effect occurs to some extent in all metals both cast and forged. Moreover, it is probable that early investigations from which the conclusion is drawn were carried out on irons of lower strength and made with less scientific control than modern irons, both factors tending to give exaggerated results. In support of this view the following may be quoted from the A.S.T.M. Symposium on Cast Iron, dealing with mass effect: "Irons produced by foundries with adequate metallurgical

control vary less in properties from section to section than irons formerly used ''—an opinion held by the B.C.I.R.A. and other workers in this field.

An early experiment to study the effect of varying section and to compare a 1 per cent.

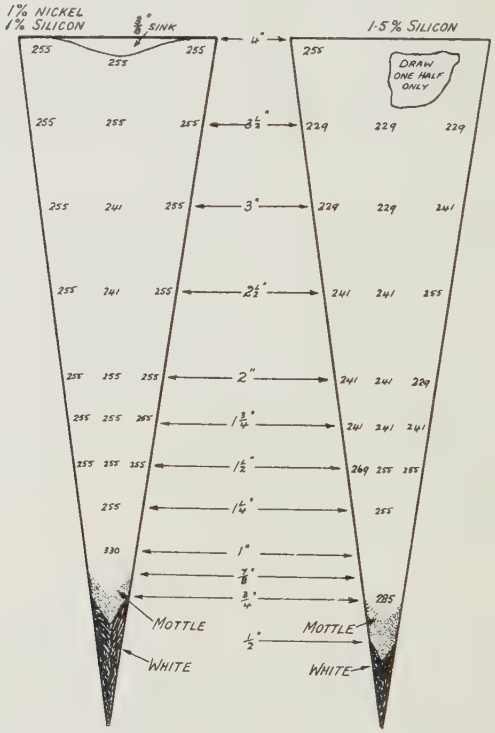

Fig. 8.—Effect of Nickel on Brinell Hardness.

nickel iron with an unalloyed iron was carried out by casting two " pyramid " bars 14 in. long tapering from a point to 4 in. square. The analysis of the iron as tapped was:—T.C., 3.17; Si, 1.02; Mn, 0.97; S, 0.09, and P, 0.3 per cent.

To one shank was added 1 per cent. of 50 per cent. ferro-silicon, and to another 1 per cent. nickel. The final silicon content was 1.46, and the nickel 0.9 per cent., so that the compositions were not quite in balance for true comparison,

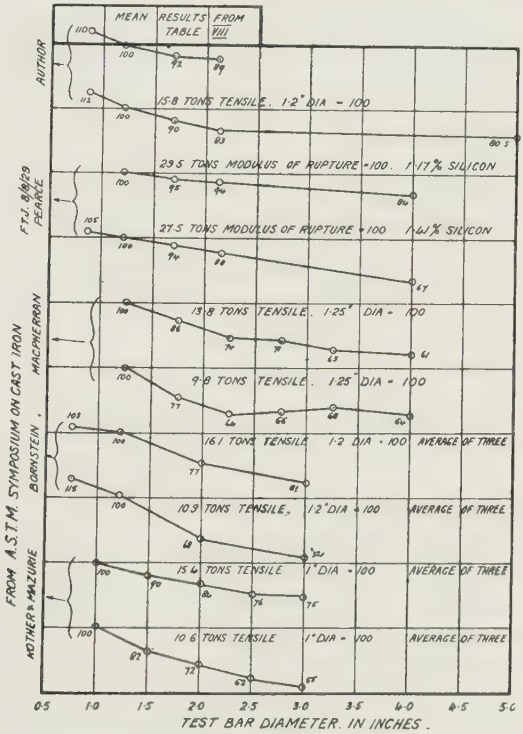
MEAN RESULTS FROM TABLE VIII
AUTHOR
15·8 TONS TENSILE. 1·2" DIA = 100
29·5 TONS MODULUS OF RUPTURE = 100. 1·17% SILICON
F.J. 8/8/29 PEARCE
27·5 TONS MODULUS OF RUPTURE = 100 1·46% SILICON
13·8 TONS TENSILE. 1·25" DIA = 100
MACPHERRAN
9·8 TONS TENSILE. 1·25" DIA = 100
BORNSTEIN
16·1 TONS TENSILE 1·2 DIA = 100 AVERAGE OF THREE
10·9 TONS TENSILE. 1·2"DIA = 100 AVERAGE OF THREE
15·4 TONS TENSILE 1"DIA = 100 AVERAGE OF THREE
10·6 TONS TENSILE 1"DIA = 100 AVERAGE OF THREE
FROM A.S.T.M. SYMPOSIUM ON CAST IRON
MOTHER & MAZURIE
0·5 1·0 1·5 2·0 2·5 3·0 3·5 4·0 4·5 5·0
TEST BAR DIAMETER. IN INCHES.

FIG. 9.—EFFECT OF SECTION SIZE ON STRENGTH (SERIES OF CURVES).

and later experience placed the ratio of nickel to silicon at 3 to 1 instead of 2 to 1 as sought in this experiment. The pyramid bars were slotted along the middle of two opposite sides and then broken across by a wedge. One half of each was planed flat for Brinell-hardness tests which gave the results shown in Fig. 8. The fractures were

also compared and the depth of chill and mottle in each clearly indicated the lack of balance between nickel and silicon. The nickel iron showed the more chill and was slightly harder throughout, but the grain size of both bars was practically identical except for the unalloyed iron being the more open at the centre of the 3-in. and 4-in. sections. It is probable that if the silicon had been low enough to match the chill of the nickel iron it would have been even

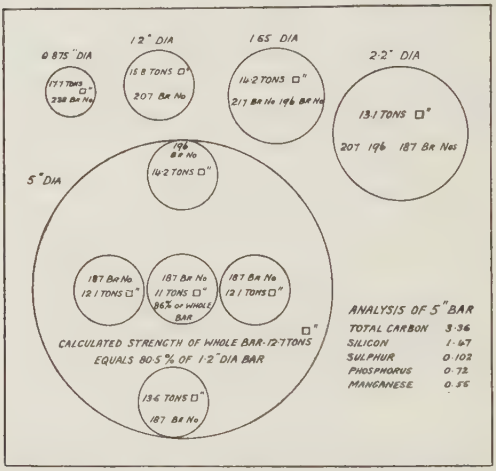

FIG. 10.—TENSILE STRENGTH AND BRINELL HARDNESS OF TEST-BARS FROM 0.875 IN. TO 5 IN. DIA.

closer to the nickel iron in hardness and grain size. Enough information was obtained to conclude that nickel addition promoted uniformity in varying sections, but the iron already in use was not affected in hardness or grain size to the extent anticipated.

The mean results given in Tables VII and VIII show the strength relationship between the four standard test-bars in use, and it was recently decided to investigate the effects of further increase in section. With this end in

view a 14-in. by 5-in. dia. bar was cast to represent the thickest section likely to be required in the mixture used. Five bars were cut—two from the extreme edge, one from the centre and two as near the centre bar as possible—and machined to 1.2 in. dia. After breaking in transverse the bottom halves were machined to 0.798 in. dia. tensile test-pieces and tested, and also tested for Brinell hardness. From the results obtained the strength of the 5-in. dia. bar was calculated. The results, and those of a complete set of bars from the same mixture, are shown in Figs. 9 and 10. The former includes the results of other workers for comparison. From this it will be seen that whilst increasing section invariably causes loss of strength, in most cases there is less relative loss with the high-strength irons, and the 5-in. dia. bar from a 15- to 16-ton iron compares favourably with the results of other investigators. The loss is only about 20 per cent. when the section is increased from 1.2 in. to 5 in., from which the conclusion may be drawn that under the conditions of manufacture, when strength is a primary consideration, the iron used will not be seriously affected by thick sections.

The results given in Table III have already indicated that the loss in transverse strength caused by machining to various depths was not severe, and Fig. 10 shows that even when the 5-in. dia. bar was machined to 0.798 in. dia. (2.5 per cent. of the original area) it still retained 86 per cent. of the tensile strength of the original bar. This confirms the results given by Pearce,[5] which showed that a bar 0.2 in. dia. machined from a 2.2-in. dia. bar retained 75 per cent. of the tensile strength of the original bar and gives a conclusion in definite values to the popular statement "the nearer the centre the weaker the iron." In this connection it may be mentioned that fractures are not always reliable guides to strength, as the centre of a thick section may show a coarse grain without necessarily being weak and thin sections of weak irons, although close grained, are not strong.

Conclusion

The investigations carried out were in the main prompted by curiosity regarding queries and popular ideas in connection with cast iron. The Paper has been prepared with a view to answering some of the queries and giving, where possible, quantitative values to the influence of various factors, the effects of which are generally appreciated but apt to be over-estimated.

The author feels there is scope for publicity by manufacturers in the direction of improving the acquaintance of users with the properties of cast iron in general and modern cast irons in particular. Probably this could best be done by a publication similar to the American Society for Testing Materials and the American Foundrymen's Association Symposium on Cast Iron, compiled in collaboration with engineering bodies. Furthermore, it is essential that the high-strength irons be included in a national specification to show that British ironfounders are not backward compared with other countries.

In conclusion, the author wishes to thank Mr. J. T. Graham (Director, Manufacturing and Engineering), Messrs. Worthington-Simpson, Limited, Newark, for permission to give the results embodied in the Paper, and several of the staff who have willingly assisted in the preparation of test-bars and illustrations, also acknowlegments are possibly due to other investigators whose work may have been unwittingly duplicated.

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DISCUSSION

Mr. J. G. Pearce said it was just the kind of Paper he had hoped some of his own earlier efforts would stimulate; the kind of Paper in which an experienced metallurgist collected, examined and analysed the results of test-bars of widely varying ranges of sizes on a range of mixtures. The proposal regarding the 1.655-in. bar would be of great interest to those members of the Institute who were concerned with framing specifications. It was quite correct that a 1.655-in. dia. bar broken at 24 in. centres gave theoretically the same breaking load as a 2-in. by 1-in. bar broken upright, tested at 36 in. centres, but, as Mr. Harbach's Table I showed, in fact the former would be stronger than the latter. Theoretically, the strengths were the same, but practically the round bar was stronger.

Round Bars have Superior Strength

It was shown in his laboratory some years ago that, other things being equal, a round bar was always stronger than a square bar. That difference had nothing to do with casting conditions, because it remained true even if the square bar was made from one which was originally cast round, and if the round bar was made from one originally cast square. The difference was due, probably, to the manner in which the stress distributed itself in transverse across the section of the bar. The result was that the 2-in. by 1-in. bar broken at 36-in. centres broke at a load almost identical with the 1.655-in. bar at 24-in. centres if the latter were made a little bit smaller. If it were made 1.6 in. instead of 1.655 in. the loads should be about the same. The difference was, roughly, about 10 per cent.

New Series of Bars Suggested

This suggested that a very convenient range might be obtained for bars for testing purposes

if, say, there were diameters of 0.8 (instead of 0.875), 1.2, 1.6, which was Mr. Harbach's new bar practically, and 2 in., each tested at a span equal to 15 dias., respectively, 12 in., 18 in., 24 in. and 30 in. A 2-in. bar 30 in. long was a big bar, but, after all, it was not so long as the 36-in. bar which had been used for so many years. Those four bars had diameters with ratios of 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, and the ratios of the areas were, roughly, 1, 2, 4 and 6. He made this suggestion because there was a sort of completeness and uniformity about the range which was very attractive when Mr. Harbach's suggested bar was considered. The big 2-in. bar, 30-in. centres, was much more convenient for testing machines than the 2.2-in. bar at 18-in. centres. Mr. Harbach had given data with respect to the relationship between transverse and tensile which would be of great value in framing specifications. There was a point to be borne in mind. Table I showed the amount of material removed by machining in a tensile test varied greatly from bar to bar. The amount of material removed was bound to affect the transverse-tensile ratio. The present tensile bars were originally based on B.E.S.A. bars for standard steels. There was no reason why tensile bars of standard diameters should be adopted for cast iron merely because they were convenient for something else.

Test-Bars from Maker's Angle

There was a great deal to be said for not removing more metal than was definitely necessary in the tensile test. He always regarded the testing question from the maker's point of view, and he had reluctantly concluded in the past that in many cases iron was tested in such a way that the maker got the worst possible result he could get. The results could be improved very considerably from the point of view of the maker as Mr. Harbach had shown, by machining the transverse bar. He could confirm all that that gentleman had said concerning the influence of machining the

transverse bar. It increased the strength considerably, and it was the standard practice in the laboratories with which he was associated. He did not say it need be done regularly in routine testing, but it was important to know what the difference was. If a result was unduly low it was possibly due to a superficial effect, and one might try the effect of machining the second bar.

The improvement also increased the ratio with the tensile test. He could also confirm the statement as to the favourable effect of the shorter span on the modulus of rupture. This was something which was not expected but cast iron behaved in that way. In theory, if the bar was shortened there was such a change in load as compensated for the shortened span; the span and the load were interdependent. It would be found that in the case of cast iron this did not happen; the shorter the span the higher the breaking load went up in proportion. The difference, however, was not great.

"Transverse Rupture Stress" Preferred

Mr. P. A. Russell, B.Sc., wished to endorse the statement that the Paper was a very valuable one to all those concerned in the framing of specifications. The data provided would be extremely helpful. He was very glad that Mr. Harbach had emphasised the transverse rupture stress of cast iron as distinct from the ordinary way of expressing the breaking load. This could not be drilled sufficiently often into the minds of the members of the Institute. Many of the obstacles in the way of transferring thought from the old 1 in. square and 2 in. by 1 in. bars would be overcome if members would use the transverse rupture stress more frequently. The necessity for matching up the old 2 in. by 1 in. bar by the 1§ in. dia. bar would be eliminated.

One of the outstanding points in the Paper which had appealed to him was the machining of the transverse test bar. It appeared to be so important that, in his opinion, provision

should be made in any future specifications for machining the bars if desired. The effect seemed to be very great. Mr. Harbach had obtained an unexpectedly high test at the top of a long runner as against the bottom. He suggested that was due to the annealing effect of the casting against the bottom of the runner, whereas the top of the runner would be much more isolated.

The Problem of Fixed Ratios

Mr. John Shaw regretted he disagreed with both the previous speakers. He had read Mr. Harbach's Paper with interest. The large number of experiments he had carried out could not but be of benefit to himself and his firm. At the same time practically all the experiments had been carried out a number of times before. As shop routine tests they were valuable, and also gave the engineer some rough idea of the ratio of the various tests and the reduction of strength with increase in section. But, he thought, no one would wish in a National Specification for the breaking transverse load to be dependent on a fixed ratio of the tensile result. He would take Mr. Harbach's own figures in the Paper, where under his closely-controlled conditions the ratio on the 2-in. by 1-in. bars fell between 2 and 1.5. This might not seem much, but if a 15-ton tensile bar was taken, and multiplied by the two ratios, the transverse might be either 30 tons or 22.5 tons, a difference of 7.5 tons. A point that was so often overlooked was the fact that the inspecting engineer did not control the foundry. While it was possible in a well-controlled foundry to establish some near ratio between these two tests, he had no hesitation in saying that the ratio would vary from shop to shop, sufficient to make it futile as a safe guide.

Span and Diameter Ratios Misleading

Mr. Harbach raised the span/diameter ratio in relation to the 2.2-in. bar. He could assure

him that this point was thrashed out in Committee and was deliberately turned down. It implied to the engineer that the same modulus figure could be obtained from a large bar as from a small one. Therefore, it might mislead. The economic side was also a factor. At that time nearly all the national spending departments insisted that the bars should be cast on. Hence there might be a bar 36 in. long to cast on a small lumpy casting. The Committee, therefore, after many experiments, made the bar as short as would yield a reasonable deflection. That their figure was right was lately confirmed by Mackenzie, who found little difference in the deflection of the 2-in. bar when tested either at 18-in. or 24-in. centres.

He agreed that with the round bars so easily skin machined, transverse tests would be more accurate if machined.

Mr. Harbach had quoted some results when using the tentative ASTM specification. These low figures were explained by the shape of the tensile piece as cast. It was of dumbbell form, and for the 1.2-in. bar was increased to 2 in. at each end. The re-annealing effect of these heavy lumps reduced the tensile in every case, and was further evidence how doubtful it was to attempt to convert one test into terms of another.

Tensile Strength Unsuitable for Classification Purposes

It was also stated that tensile would probably prove the more suitable means of classification for high-strength iron. He disagreed with this statement. With this type of border iron it had been proved over and over again that while there might be a high tensile, the transverse often failed. Hence the present search for a suitable impact machine. The impact results put before the A.F.A. were disappointing when compared with the tensile results. The transverse test gave a better idea of the quality of the iron.

The Founder and the Large Test-Bar

While it was generally accepted that the time was ripe for a revision of Specification No. 321, or the framing of an entirely new specification to bring the increased strengths of modern cast iron into line, it was open to doubt if the tendency shown by some members of the Committees, both here and in the States, would be acceptable to the heavy founders. To cast a 2.2-in. bar from either crucible, small oil or electric furnace that gives high tensile tests was one thing, to make a casting of 15 to 20 tons with this type of metal was quite a different proposition. How far such a metal was even suitable for a large number of castings that now have to meet a specification was open to serious doubt. From a careful search over a number of years he had only found one 2.2-in. dia. bar that was cast from the same ladle of metal as a large casting that yielded 21 tons per sq. in. That mixture contained 80 per cent. steel (MacPherran). It was invariably found, both here and in the States, that the chief advocates for the large bar to yield the same load per sq. in. are those makers of peanut-sized castings or technical advisers, who, like the signposts, point the way (often wrongly), but have never to travel that way.

AUTHOR'S REPLY

The 16-in. × 24-in. Bar

Mr. Harbach, in reply, said that the results in the original state were determined more or less to satisfy his own curiosity with regard to certain points. The fact that they had got into print, and were presented to the Conference, was due entirely to the President, who regarded them as being useful material. It was gratifying to find that Mr. Pearce and Mr. Russell found so much to confirm their own views. Personally, he was rather inclined to take a serious view of the 1.6-in. dia. by 24-in. bar, because that was actually the first round bar that he ever used, and was really used prior

to the adoption of round bars as a standard specification. Therefore, he had taken a sort of fatherly interest in it. He was glad to hear Mr. Russell endorse the need for expressing transverse strength as rupture stress instead of breaking load, as this was the only method whereby the results from different sizes and shapes of bars became comparable, but, even if the method became well established there would still remain a number of people interested who thought of strength in terms of the breaking load of a 2-in. by 1-in. bar—some specifications still call for tests on this bar—so that, apart from other reasons, the use of a 1.6-in. dia. by 24-in. bar would have advantages.

Effect of Machining on Transverse Tests

With regard to the effect of machining on transverse tests, he was inclined to think that it was not possible to make the iron any stronger; therefore it was, to some extent, an advantage to remove the variables which were causing a low result. The relationship to the casting was a different thing altogether, but as long as there was a constant means of testing it constituted a step forward in determining what was the strength of the casting.

Mr. Russell had raised a point with respect to the top and bottom of a 9-ft. runner. He agreed that the bottom was annealed, and being in a pit would account for it, but only the day before he had had results from one which was cast in a box, 5 ft. long and $1\frac{3}{4}$ in. diameter. The top half was 11.5 tons and the bottom 11.1 tons. It was not a difference of great magnitude, but nevertheless it showed the same effect, although there was no annealing action in the box as there was in the pit.

Transverse and Tensile Ratios

He very much appreciated Mr. Shaw's contribution to the discussion as it was well known he had given considerable attention to this particular subject. He was glad to find the results given were considered useful in establishing

approximate ratios between transverse and tensile strengths and the effect of increasing section on strength. It was not suggested that a constant ratio would be obtained in practice so that tensile strength could be accurately calculated from transverse strength, in fact in the conclusion on this point the writer stated " the determination of tensile strength is preferable to estimation from transverse strength."

On the other hand, in Mr. Shaw's calculations the widest ratios for 2 in. x 1 in. bars (2 to 1.5) were taken, but in the results from which the curve was compiled the average was close to 1·8 and 1.7, and only five results were outside the range 1.9 to 1.6; moreover they were not obtained under closely controlled conditions, but from a variety of mixtures over a long period.

High Tensile and Low Transverse

In the main the author suggested that under controlled conditions the tensile could be calculated within ± 8 per cent. or less, compared with ± 14 per cent. shown by Mr. Shaw. He fully agreed that the ratio might vary somewhat between different foundries due to factors which affect the relation between tensile and transverse beyond the usual ranges. In fact this point is mentioned when considering Fig. 5, " factors causing high tensile strength may not necessarily raise the transverse to the same degree," which in a modified form bears out Mr. Shaw's remark that " high tensile irons often fail in transverse," although failure would naturally depend on the minimum transverse required for a given tensile, and results indicated that if the tensile was doubled the transverse could only be expected to increase about 50 per cent.

In the event of a high-test iron giving unexpectedly low transverse results, it might be mainly due to skin defects which, whilst having a marked effect on the breaking load, would have very little effect at working load.

It was admitted that, to people directly concerned with the properties of cast iron, the

transverse test was more informative than the tensile test, but to the majority of users and designers who were not so similarly interested the tensile strength was the one chiefly considered so that classification on this basis, together with appropriate transverse figures, would serve both maker and user. So far as a fixed ratio in a specification was concerned, this would only apply as a basis for obtaining the relation between the minimum transverse and tensile required as the actual test results could vary both above and below the orignal ratio providing they complied with the minimum requirements.

Effects of Span/Diameter Ratios

He was aware that Mr. Shaw had given considerable time and thought to the effects of varying the span/diameter ratio. Although he could not claim the same lengthy experience with the 2.2-in. dia. bar, the results of tests on the 1.2-in. and $1\frac{5}{8}$-in. dia. bars had shown that when the E value was calculated from the total deflection of bars having a span/diameter ratio of 15 : 1 close agreement was obtained, but with both sizes of bars broken at 12-in. spans the E value dropped roughly in proportion to the decrease in span and then agreed fairly closely with the results of the 2.2-in. dia. bar.

With regard to the suggestion of Mr. Pearce for a 2-in. dia. by 30-in. bar, and Mr. Shaw's objection on account of the length, whilst it was admitted a cast-on bar of this length might prove unsuitable for some castings, recent specifications tend to permit the use of bars cast separately, and when a full-length bar required to be cast on had proved difficult, there had been no objection to the arrangement that a satisfactory tensile result from a shorter bar should be sufficient for acceptance.

It was gratifying to note that Mr. Shaw confirmed that a new specification was required to cover the higher-strength irons now available, and he agreed that specifying the high-strength

irons for large castings would often be undesirable, and, in fact, he would go further by saying that such irons would often be unnecessary if reasonable safety factors for irons of medium strength were used. Hence the suggestion that efforts to acquaint users with the properties of cast iron would be rewarded by simplifying the founders' problems and establishing reliable information in the minds of users and designers which would, amongst other things, cancel out ideas that cast iron was still 8 to 10 tons tensile, and a safe working stress should not exceed 2,000 lbs. per sq. in.

It was felt strongly that the more users and manufacturers could meet on common ground the more readily they would appreciate each other's problems to the ultimate advantage of both sides.

DISCUSSION BY EAST MIDLAND BRANCH AT DERBY

Mr. S. E. Dawson said by the way Mr. Harbach plotted his curves in terms of tensile and transverse, and not in analysis, he had eliminated something of the facts of varying analysis, which might have given some bearing on these results. The factors were so largely controlled by casting conditions and rate of cooling. Mr. Harbach's tests had shown differences of plus and minus 8 per cent. The rate of cooling could give greater differences than that, but the fact of only 8 per cent. is probably because his conditions were rather constant. The sand moisture was also probably controlled. If he had to go where the conditions were different, the 8 per cent. might be considerably increased. He was quite right in taking large numbers of tests. He (Mr. Dawson) wanted to stress that, in trying to correlate the various test-bars in use, one should couple the making of test-bars with the conditions under which they would be poured, as they could cause so great differences in tensile and transverse, and it was the ultimate strength that counted. One should look on test-bars as a test of the metal and not

of the castings. If one put in a 15-ton metal, one could only let the sections take care of that in the castings. The very big difference that could be produced could be instanced by casting the same metal into a semi-chill and a sand mould. The structure was entirely different. In the semi-chill there was a dendritic structure, and in the sand it was absent. It may be that in the 1.6-in. bar Mr. Harbach had struck a happy size for the cooling of the metal he was using. Had he taken some other size, he might have had a different set of results. The results of his tests after removing 5 per cent. of the metal by machining, were surprising, as the metal removed was the best of the metal.

Mr. P. A. Russell said Mr. Harbach had been more successful than any other worker whom Mr. Russell had read. The author had shown a curve giving differences of plus and minus 8 per cent. Mr. Dawson attributed this to the conditions, and he (Mr. Russell) agreed. He had examined an assortment of bars from different sources, and had had results that were widely different. One could get 15 tons tensile with high phosphorus and low carbon, and 15 tons with low phosphorus and high carbon. He was glad that Mr. Harbach had emphasised the importance of modulus of rupture. If only people could be converted to using modulus of rupture instead of the load figures, they would find that their results would convey more to them. It was important that the correction factor should be applied, and it was easier when converted to modulus of rupture than when using actual stress.

Mr. J. Lucas said Mr. Harbach had mentioned that his test-bars were cast vertically; why did he prefer that? It was well known that the test-bars were an indication of the metal, but there were different things in the castings. One might find out what the metal was like, but is not a true indication of the casting. Mr. John Shaw, in discussing the Paper at the conference, had referred to the fact that Mr. Harbach had brought in another size of test-bar.

There were too many bars for the foundryman to work to, and he sometimes envied the man who had no bars to bother about; his work must be easy. Finally, he asked for a definition of "modulus of rupture."

Mr. J. F. Driver asked whether any results had been obtained by such a machine as the Izod impact tester.

AUTHOR'S REPLY

Mr. Harbach, in reply, said the number of bars actually broken numbered between 500 and 600. He had determined to get as many results as he could. If the tensile were doubled the transverse increased on 50 per cent. It had been his intention to co-operate with the foundry so that it could be shown that the tensile strengths were not to be expected to increase at the same rate as the transverse. As far as variations in different practice, he had shown that other people's work could vary widely, so that he could not claim that his figures were applicable to other firms' practice, but they applied to his own and gave a clue. In five mixtures he had plotted these results, in the hope that they would have some difference, but nothing came of it as they were all patchy. His combined curve had shown all the results in the other curves, but did not include the 1.65-in. bar, only the 1.2-in. bars in that curve. So far as strength of bars in relation to casting went, that would always be difficult. Mr. Lucas had asked why he had cast bars on end. He could only say that that had been the practice before he went to the firm and he had carried on with that practice. The foundry thought they achieved the best results from the vertical-cast bars. Cast flat there was a tendency in the 2-in. by 1-in. bars to have blowholes on the face.

It is necessary when taking tensile tests from parallel bars, to machine the middle to ensure breaking away from the grips. In America, 1.2-in. dia. tensile bars with wide ends have been used, but as Mr. Shaw has pointed out, the wide ends anneal the bar and lower the results so that more was lost than gained.

As to the 1⅝-in. bar being another worry to the foundry, he was of the opinion that it was the reverse. The round bar was better for the foundry. If the foundryman was using round bars, a 1.6-in. bar would give a load that would match with the foundryman's idea of the 2-in. by 1-in. bar.

To record in terms of modulus of rupture, as one must if he wished to compare different sized bars, one had to take into account the size of the bar. If a bar was extended it would be weaker. The modulus of rupture took into account span and size of bar, and the result was in tons per sq. in., and compared any size of bar with another.

With regard to impact tests, he had no machine available. In any case the Izod would be too severe. Of the repeated impact test he had taken a few, but not to compare with the bars. There was no definite relationship between impact and strength, but in the main, as strength increased, the impact test also increased. As for plotting the results, it would be more patchy than those he had given.

A vote of thanks to Mr. Harbach was proposed by Mr. E. R. Walter, of Lincoln, and seconded by Mr. T. Goodwin, of Derby, and Mr. Harbach suitably acknowledged.

AUTHOR'S WRITTEN REPLY

During the discussion, a request was made for the definition of modulus of rupture, but time did not permit a reply in detail. The following has since been written in an endeavour to explain how it is calculated, and also how calculations for the correction of the breaking loads of incorrect sizes of bars are made.

Effect of Span, Breadth, Depth and Diameter

The breaking load of a transverse bar varies inversely as the span. Thus a bar doubled in span will break at half the load, or if the span be halved the load will be doubled. Therefore, for the same section and strength, load times span will be constant. This

calculation is only required, as a rule, when modulus of rupture is required.

For a rectangular bar the breaking load varies as the breadth and as the square of the depth. Thus a bar 2 in. broad will break at twice the load of a bar 1 in. broad and a bar 2 in. deep will break at four times the load of a bar 1 in. deep, always providing the other dimensions and span remains the same.

Corrected load for error in breadth is :—

$$\frac{\text{Actual breaking load} \times \text{standard breadth}}{\text{actual breadth}}$$

Example.—A bar 1.1 in. broad instead of 1 in. broad breaks at 30 cwts.

$$\text{Corrected load is } \frac{30 \times 1}{1.1} = 27.3 \text{ cwts.}$$

Corrected load for error in depth is :—

$$\frac{\text{Actual breaking load} \times \text{standard depth}^2}{\text{actual depth}^2}$$

Example.—A bar 2.1 in. deep instead of 2 in. breaks at 30 cwts.

$$\text{Corrected load is } \frac{30 \times 2 \times 2}{2.1 \times 2.1} = 27.2 \text{ cwts.}$$

Corrected load for errors in breadth and depth is :—

$$\frac{\text{Actual breaking load} \times \text{standard breadth} \times \text{standard depth}^2}{\text{actual breadth} \times \text{actual depth}^2}$$

Example.—A bar 1.1 in. broad by 2.1 in. deep instead of 1 in. broad by 2 in. deep breaks at 30 cwts.

$$\text{Corrected load is : } \frac{30 \times 1 \times 2 \times 2}{1.1 \times 2.1 \times 2.1} = 24.7 \text{ cwts.}$$

For a round bar the breaking load varies as dia.^{3} ; thus a 2-in. dia. bar would break at eight times the load of a 1-in. dia. bar ($2 \times 2 \times 2 = 8$; $1 \times 1 \times 1 = 1$) for the same span.

Corrected load for error in diameter is :—

$$\frac{\text{Actual breaking load} \times \text{standard dia.}^3}{\text{actual dia.}^3}$$

Example.—A bar 1.25 in. dia. instead of 1.2 in. dia. breaks at 2,500 lbs.

$$\text{Corrected load is : } \frac{2{,}500 \times 1.2 \times 1.2 \times 1.2}{1.25 \times 1.25 \times 1.25}$$

$$= 2{,}210 \text{ lbs.}$$

Calculation of Transverse Modulus of Rupture

To show transverse results without having to give full details of bar dimensions or to compare the results from bars of different sizes and shapes, it is necessary to convert the transverse breaking load to transverse modulus of rupture.

This gives the transverse strength in tons (or lbs.) per sq. in. and is calculated by means of a formula which takes into consideration span, breadth and depth of rectangular bars, or span and diameter for round bars, on lines similar to those shown above. When the load is in tons and the dimensions in inches the result is in tons per sq. in., but if the load is in lbs. or cwts., it must be converted to tons or a factor introduced into the formula to equal the conversion.

Transverse modulus of rupture in tons per sq. in.

$$\frac{\text{Breaking load in tons} \times \text{span in inches}}{4 \times \text{modulus of section}}$$

The modulus of section for a rectangular bar is :—

$$\frac{\text{Breadth} \times \text{depth}^2}{6} \therefore 2 \text{ in.} \times 1 \text{ in.}$$

$$= \frac{4}{6} \text{ and } 1 \text{ in.} \times 1 \text{ in.} = 1/6.$$

Example 1.—A bar 2 in. × 1 in. × 36 in. (2 in. being the depth) breaks at 30 cwts. 30 cwts. = 1.5 tons, so the calculation is :—

$$\text{Modulus of rupture} = \frac{1.5 \times 66}{4 \times \frac{4}{6}}$$

$$= \frac{1.5 \times 36 \times 6}{4 \times 4} = 20.25 \text{ tons per sq. in.}$$

Example 2.—A bar 1 in. × 1 in. × 12 in. breaks at 25 cwts. (1.25 tons).

$$\text{Modulus of rupture} = \frac{1.25 \times 12}{4 \times \frac{1}{6}}$$

$$= \frac{1.25 \times 12 \times 6}{4} = 22.5 \text{ tons per sq. in.}$$

The modulus of section of a round bar is :—

$$\frac{\pi \text{ dia.}^3}{32} = 0.0928 \times \text{dia.}^3$$

Example 3.—A bar 1.2 in. dia. × 18 in. span breaks at 2,000 lbs. (0.893 ton).

$$\text{Modulus of rupture} = \frac{0.893 \times 18}{4 \times 0.0982} \times 1.2 \times 1.2 \times 1.2 = 23.6 \text{ tons per sq. in.}$$

The above shows complete calculations for three bars, but as in all standard bars the span and section for each bar are constant, the part of the formula dealing with them (including the conversion of lbs. or cwts. to tons) can be simplified to a single factor, so that all that is necessary to calculate transverse modulus of rupture is to multiply the breaking load by the factor appropriate to the bar tested. These are given below :—

1 in. × 1 in. × 12 in.-lbs. × 0.00803 = tons sq. in., or cwts. × 0.9 tons sq. in.

2 in. × 1 in. × 36 in.-lbs. × 0.00603 = tons sq. in., or cwts. × 0.675 = tons sq. in.

$\frac{7}{8}$ in. dia. × 12 in.-lbs. × 0.0204 = tons sq. in., or cwts. × 2.28 = tons sq. in.

1.2 in. dia. × 18 in.-lbs. × 0.0118 = tons sq. in., or cwts. × 1.32 = tons sq. in.

2.2 in. dia. × 18 in.-lbs. × 0.00192 = tons sq. in., or cwts. × 0.215.

It must be borne in mind that the factors only apply to breaking loads of bars of standard size (or after allowance has been made for incorrect size). The factors for the direct calculation of modulus of rupture from the breaking loads of round bars of incorrect size were given in Table II of the Paper.

All the calculations shown above are theoretical and may not be quite true in practice. The extent of the differences to be expected between rectangular and round bars ; bars of different sizes and bars tested at various spans were also given in the Paper.

CASTINGS

By W. Machin and M. C. Oldham (Members)

(*Also read before the Lancashire Branch*)

It is the authors' intention in this Paper to make the various points on castings manufacture as practical as possible. It is thought by deal-

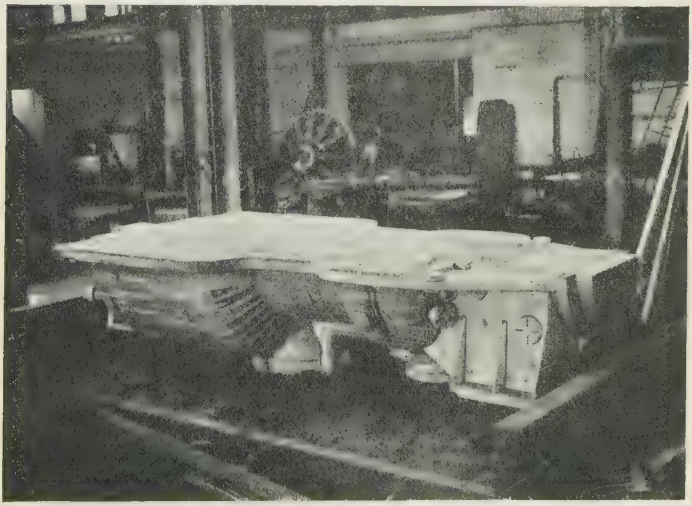


FIG. 1.—PATTERN OF A CAST-STEEL BOTTOM-HALF TURBINE, SET IN CASTING POSITION.

ing with the matter on these lines many of those associated with the craft will better understand the points raised, and thus influence them to give closer attention before the pattern is put into the sand, thereby eliminating many of the defects seen in castings. So many variables are associated with the manufacture of castings that the degree of success obtainable depends mainly on the decisions made by those responsible for the

methods of procedure. The variables referred to concern work on moulds and cores, materials and metallurgical processes.

The predominant factors, therefore, to obtain successful production are experience, coupled with careful thought and study, before commencing manufacture, and a definite line of co-operation with those concerned on the metallurgical side of the industry. Every design presents its peculiar problem, more or less, in that the casting has to comply with the exacting clauses of modern specification and inspection relative to the particular service required from it as a finished product. Progress is being made only

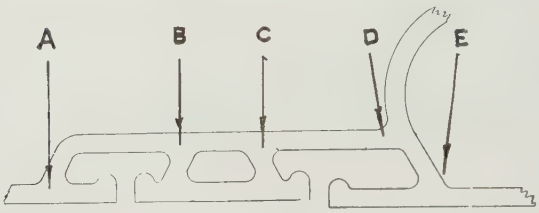


FIG. 2. — CHANGING THICKNESSES ARE SEEN AT JUNCTIONS LETTERED A, B, C, D, E.

by the close co-operation of designer, patternmaker, moulder, coremaker and metallurgist, and there has been evident, during recent years, an increasing tendency to establish this collaboration in the foundry. The generally accepted excellence of castings now being produced may be attributed to such co-operation.

Castings have to be supplied in accordance with the designer's conception of what is essential to meet the requirements of service, and, modern construction specifying minimum weight, exhibit variations in thickness of an astonishing nature. The disposition of masses of metal at local junctions is a feature of present-day design, and

frequently it is necessary to consult the designer to suggest some modification here or there to assist the foundry. Invariably the suggestions put forward and accepted do ease the problems, but, generally, due to the light sections in which modern castings are designed, chiefly arising from the improvement of materials, modifications suggested by the foundry cannot always be accepted in full, though as much as possible is done to meet them. Problems are surmounted only by most thorough investigation over the entire range of manufacture.

Variable Thicknesses

Thicknesses vary considerably in modern structural design, in some instances from 1 to 20 in.

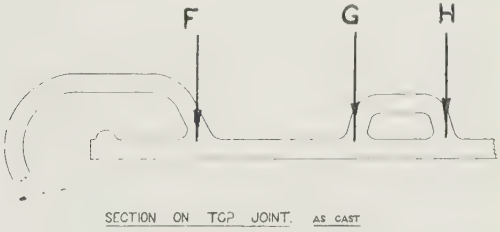


FIG. 3.—CHANGING THICKNESSES ARE SEEN AT JUNCTIONS LETTERED F, G, H.

The variations shown in the steel casings and valves required for temperature and pressure service in land turbines, range from $1\frac{1}{2}$ to 14 in. Steel castings for marine-engine turbines, range in thickness from $\frac{1}{2}$ to 3 in., and for service in gun mountings, the thicknesses range from $\frac{1}{5}$ of an in. to 3 in.

Intricacy in design, with its inseparable variations in thickness, presents a problem, on the solution of which depends the production of castings to meet the requirements of modern engineering.

Numerous drawbacks may be involved in the manufacture of the mould, and most thorough

examination of thicknesses is vital. There must be definite assurance that the mould and core surfaces will withstand the impact and wash of molten metal, and the mould has to be so constructed as to offer no resistance to contraction. The composition of the metal, and efficient mixing and melting of the diverse alloys in present-day use, call for expert metallurgical supervision.

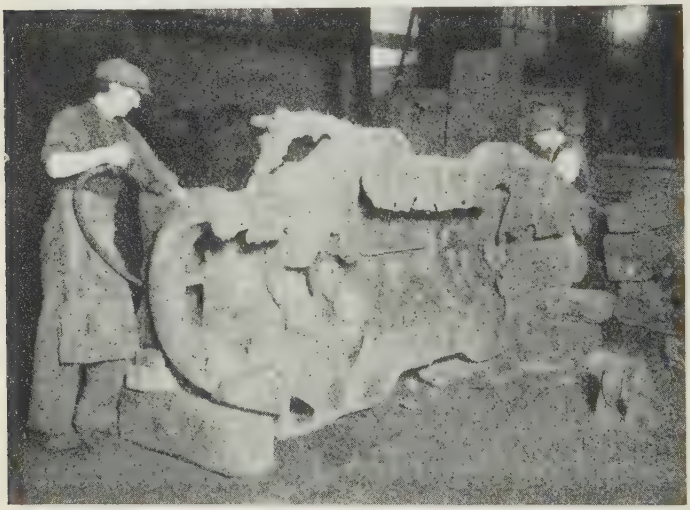


FIG. 4.—SHOWS THE FEEDERS FOR A TURBINE CASTING.

Patternmaking

Following the receipt of the designer's blueprint, experience and skill of the highest order is necessary in the manufacture of the pattern, in accordance with the requirements of the foundry, if castings of first-grade quality are to be efficiently produced on economical lines. The co-operation of the foreman patternmaker is therefore necessary, so that the pattern can be made in accordance with the method adopted by the foundry, thus facilitating the moulding, coremaking, running and feeding arrangements.

The methods of making patterns vary in accordance with the different metals in which the castings are required, viz., steels, irons and the numerous non-ferrous alloys. The method of feeding a steel casting differs entirely from that of iron, but a few of the irons and non-ferrous alloys are similar, viz., Lanz Perlit and Emmél irons, alloy irons and some of the bronzes or brasses.

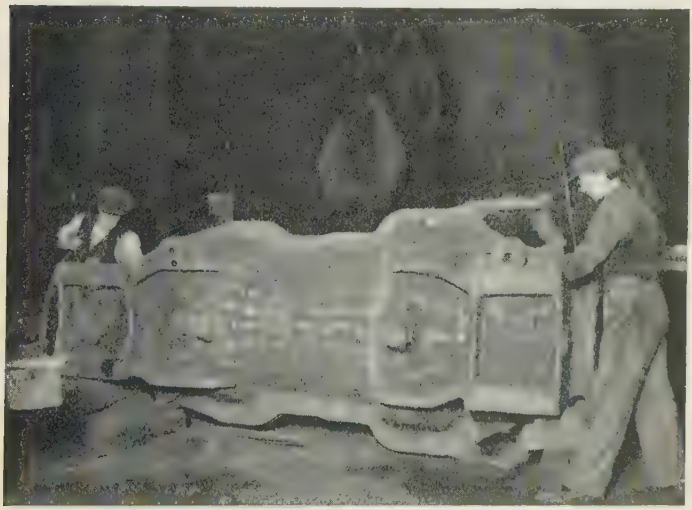


Fig. 5.—Shows the Reverse Side of Fig. 4.

A pattern for use in a steel foundry requires the most consideration, as steel contracts more than iron or brass, and the casting temperature is higher, with earlier commencement of the freezing stage. In addition, shrinkage, consequent on the cooling of thick sections, has to be made good by a flow of liquid metal, from what are known as feeders, risers or heads. The pattern must be constructed in a manner which will enable the foundryman to cast his mould in the correct position, thus permitting him to

place the feeders over those parts where changes in thickness occur in the casting. Some illustrations of this point will be interesting.

Methods of Running

Note that the pattern shown in Fig. 2 is placed in position with the joint face uppermost in order that feeders can be placed over those parts where three lanes of metal meet at A, B, C, D and E. The same point is illustrated in the sketch at F, G, H in Fig. 3.

The feeders used over these parts of the casting can be seen in Fig. 4, showing the actual casting being dressed, whilst Fig. 5 shows the

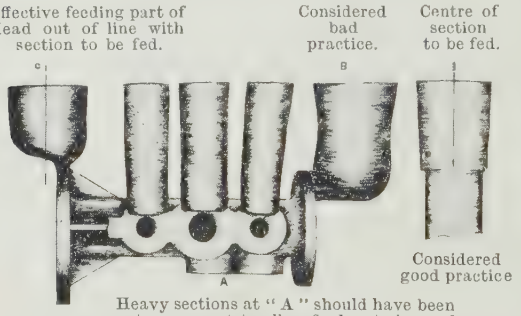

Effective feeding part of Head out of line with section to be fed.
Considered bad practice.
Centre of section to be fed.
C
B
A
Considered good practice
Heavy sections at "A" should have been cast uppermost to allow feeders to be used.

Fig. 6.—Feeding Details.

reverse side of the casting shown in Fig. 3—the side of the casting would have been uppermost had it been made in iron, an instance of the importance of co-operation between the patternshop and the foundry.

The methods of running and feeding vary considerably, and in this connection the first report published in 1933 by the Steel Castings Research Committee of the Iron and Steel Institute, was extremely illuminating in its disclosure of the variety of methods adopted by founders. The report on the various castings made from the one design for the purpose of that investigation plainly indicated that each separate method

adopted resulted in failure. Had information been available as to the exact detail of the separate methods under which those castings were made, the sands used in the manufacture of moulds and cores known, useful criticism might have been offered by many of those interested. The illustrations of the report referred to indicated that the methods of running and feeding were, in most cases, not those likely to succeed.

This was the opinion of many of the founders turning out steel castings for pressure work, and such being the case, a more general discussion

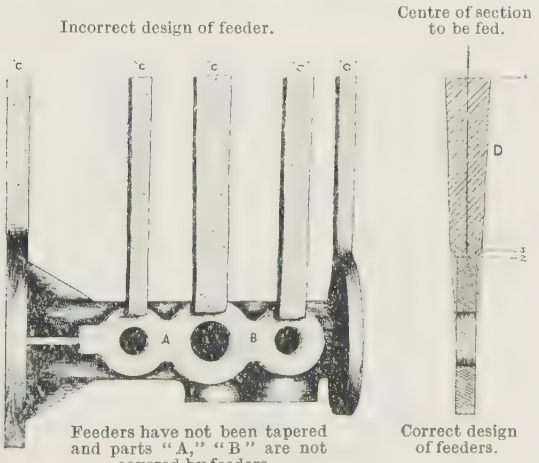


FIG. 7.—FEEDING DETAILS.

from the practical side might have assisted further investigations on the same subject. The methods of running and feeding the different metals vary considerably. It is considered that the feeder giving the most satisfactory results is one just large enough to be effective, the dimensions varying with the shape and thickness of the section to be fed, with easy tapers preferable. The centre of the thickness of metal being the part required to be fed, should be the point to receive the centre of the feeder, as that is invariably where shrinkage occurs.

Shrinkage

Shrinkage can be dealt with under three headings:—(1) Contraction in volume of the liquid metal from the temperature at which it is cast, to that at which it is just on the point of solidification; (2) contraction in volume in passing from the molten state at freezing point to the solid state at freezing point; and (3) contraction in volume from the point of actual solidity to normal temperature, this being the contraction

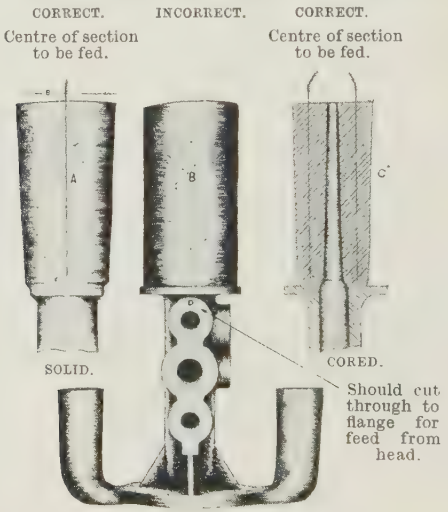


FIG. 8.—FEEDING DETAILS.

shown on the patternmaker's rule. The defects due to inefficient feeding come under headings (1) and (2), and hot tears under heading (3).

In order to demonstrate the different methods under which a number of steel castings of exactly the same design were actually fed, three illustrations, shown separately in Figs. 6, 7 and 8, will be interesting, explained in detail.

In Fig. 6, A shows how the job has been moulded, with the heavy sections in the lower

half of the mould, thereby eliminating the feeding; B shows a very unsatisfactory type of feeder, used no doubt owing to easy removal in the dressing shop and cutting out extra work. This type of feeder is considered too bulky, and is unsuitable as regards position, owing to it not being placed directly over the part to be fed; the correct method of using a round feeder of this description will be observed on the right-hand side of Fig. 6; and C shows the same type of feeder used on the top of the flange in a position considered good practice, but it will be noted that the centre of the feeder is out of line

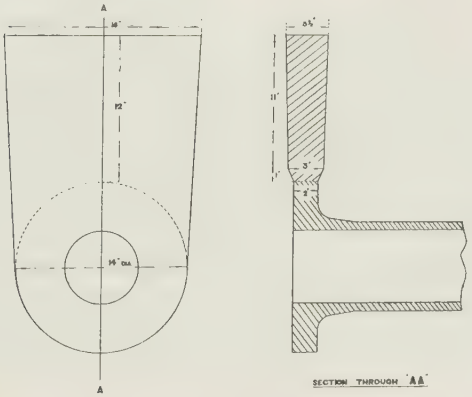


FIG. 9.—FEEDER ON VALVE FLANGE.

with the centre of the flange. As the centre of every feeder is obviously the last part to solidify, it follows that it is the most effective feeding part. The shape of the feeder "C" is also too bulky and will bring about too much heat in its vicinity.

In Fig. 7 is seen another idea of feeding; it shows five feeders at C of very unsatisfactory design, as they are too small, the portions at A and B being insufficiently covered. In addition, the feeders have no taper as that shown at D, which is considered a correct design to use on a steel casting of this type. It will be

observed that the centre of this feeder covers the centre of the part to be fed, and also the feeder D is not too bulky, being of gradual taper.

Fig. 8 shows another idea of casting the same job in a vertical position, and feeding is done in quite a different manner. This method is also unsatisfactory, owing to side feeders being employed on the flange cast at the bottom. Feeding cannot be effectively carried out in this manner, and the arrangement is not a good one from the point of view of contraction. The feeder used at B is of a plain tube type, and the core was carried through at full internal diameter size of the casting. In this instance the portion

Fig. 10.—Radiograph of Defect in a Steel Casting.

requiring to be fed, is not so effectively covered as that shown at C, which is considered correct, the centre of the feeder leading directly into the thick part, where the flange joins the body of the valve. The feeder shown at A is also considered a better type to use were the same job cast in solid form.

It will be noticed that feeder A is tapered from 6 to 8 in., and is placed over the centre of the casting. The shrinkage, therefore, taking place from the 6-in. dimension, is well covered and made good by the extra bulk of metal in the taper to 8 in.

Fig. 9 illustrates a feeder considered to be the correct type to use on a valve flange. The effec-

tive method by which the flange and fillet are fed are noteworthy, as they do not localise the temperature unduly.

The shape of the feeder with its generous height, necessary to hold up the bulk of metal in the body of the mould, thereby affording the desired gravity pressure, is also good practice. The running of moulds for steel castings needs to be carried out in a manner to ensure a supply

Fig. 11.—The actual Defect disclosed by the Radiograph (Fig. 10).

of hot metal in close proximity to the feeders, as near to the top of the mould as can be conveniently arranged. It has been found in practice that the most satisfactory results are obtained by this method, assuming all other conditions in the mould are suitable.

Unless the running arrangements and general conditions referred to are carried out satisfactorily on the lines described, shrinkage cavities of a type well illustrated in the radiograph shown in Fig. 10 will result. This effectively shows the shrinkage defects which can develop

at junctions where three lanes of metal meet, as shown in Figs. 2 and 3.

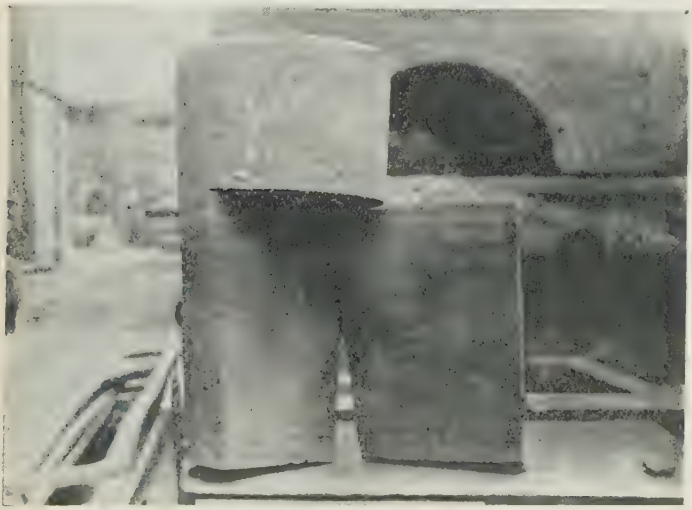
Fig. 11 shows a section cut from the casting, and the shrinkage cavity illustrates the actual defect disclosed by the radiograph (Fig. 10). Any position at which feeders may be placed can never be satisfactory unless hot metal can be supplied to them, and obviously the runner or runners must be placed in position to ensure such supply. To illustrate this point more clearly,

11A.

two photographs, Figs. 11A and 11B, of a sectioned feeder taken from a casting which was bottom-poured, should be of interest. Fig. 11A shows the feeder with shrinkage at the bottom portion of the casting, and Fig. 11B illustrates how solid the metal is in the upper portion. It will be appreciated, therefore, how important it is that the hottest metal should be in the feeders at the finish of the casting operation.

A method brought into use where possible, is that of adding hot metal to the feeders by means

of the ladle, after the mould has been cast. This practice is good, but not always convenient over a large number of feeders. In addition, it frequently delays other operations, such as the quick break-up of the mould before the easing operation is commenced. The correct and more reliable method of feeding and running a casting may not be adopted by the founder, owing to the cost involved in that particular method. Risks may be taken to get a job out on price



11B.

and another method selected, the expenses connected with which may promise a margin, but more often than not the procedure results in inferior-quality castings being produced.

The adoption of methods entailing efficient feeding and running may be more definitely observed in those foundries where pressure castings are manufactured. Steel castings of high quality cannot be produced, unless the supervisor provides facilities for satisfactory feeding, and running, before the making of the mould.

Some illustrations, Figs. 12 to 18, of the extra moulding work necessary in the making of moulds to obtain such facilities present material of interest.

The mould shown in Fig. 12 has had to be made with a number of loose pieces, or drawbacks, to obtain good running and feeding conditions. The first drawback has been inserted, also the prints to receive the steam-passage cores

Fig. 12. Bottom Half of Mould for L.P. Turbine Casing showing the Bearing Side being Cast uppermost.

in the large core at the rear can be seen, the cores as shown in Fig. 12 having been removed to illustrate this.

It would have been much easier to mould this job the reverse way, as would have been the case in iron, as feeding and running arrangements would have been entirely different. The sections of metal which must necessarily be fed, such as those that vary considerably, encircling the bearing cores, and those around the core

which form the steam passage are noteworthy. At these parts, sections similar to those in Figs. 2 and 3 exist.

Ample provision has to be made to ease the casting quickly. The top half of the mould is so constructed that the moulding box can be expeditiously taken off, to allow easy access for further removal of loose pieces and other parts, which would otherwise retard contraction. Similar methods have been employed and a large quantity of loose pieces have to be allowed for in order to facilitate correct running and feeding.

Feeding Iron and Non-Ferrous Castings

In the running and feeding of iron and non-ferrous castings, particularly the former, difficulties are somewhat modified, mainly on account of there being less contraction. In addition, more extended freezing ranges and lower casting temperatures assist the foundryman considerably. It must not be inferred that troubles are never experienced in these alloys, but happily they are not so formidable as those connected with the manufacture of steel castings. Some illustrations of iron castings (Figs. 19 to 23) will indicate that the methods adopted are free from much of that additional work inseparable from the manufacture of moulds for steel castings.

The core for the casting in Fig. 21 was placed in the bottom print of the mould, the reverse position for a similar casting in steel. Fig. 22 would have been made in the bottom half of the mould had it been in steel, in order to facilitate feeding.

Spray runners around the top and bottom flange have given perfect results. These runners can be arranged from two, three or four down pegs over channels cut all around the joints. The sprays from these channels into the flanges are of equal size, and spaced equidistant to ensure even cooling. Feeders can be arranged from the side of the top flange opposite, that is, in between the runners or sprays, but they must all be of the same dimensions and equally spaced.

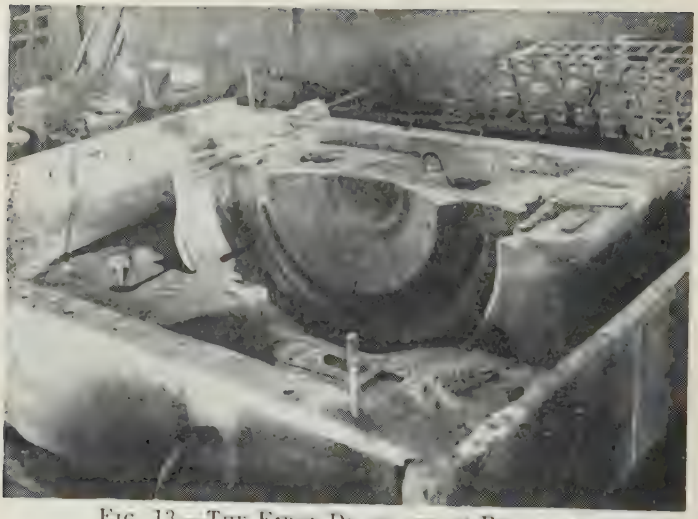


Fig. 13.—The First Drawback in Position.

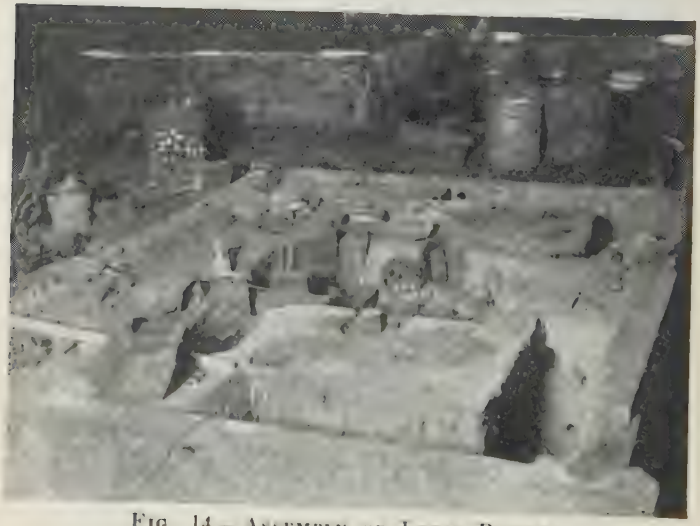


Fig. 14.—Assembly of Loose Pieces.

Fig. 15. Complete Assembly of Loose Pieces in Bottom Half of Mould in readiness for placing Top Half in Position.

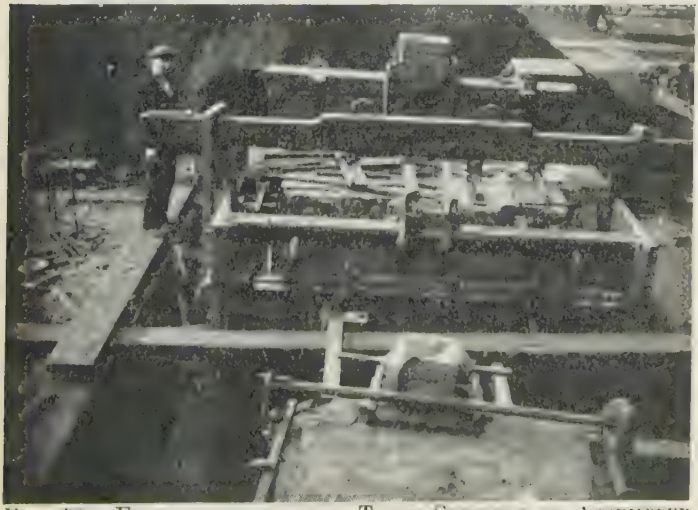


Fig. 16.—Feeders placed over Thick Sections in Assembled Bottom Half of Mould.

Various kinds of feeders are shown in Fig. 24, all having been recommended by different founders.

Feeder A is of the same thickness as the casting and should cool at approximately the same rate. In this case the extra metal cannot be effective should any feed be required for the casting, its only service being to catch any dirt rising to the top of the mould.

Feeder B is larger in bulk, but it will be noticed that the centre of the head is placed so as to feed directly on to the radius at the back of the flange. The remarks regarding feeder B apply also to feeders C and D.

Feeder E shows a different design, tapered on both sides so that the centre of the feeder is directly over the part requiring feeding, viz., the cross section where the flange meets the vertical wall.

Of the numerous types of feeders, heads or risers seen or tried out over long personal experience, the best design appears to be that which places the centre of the feeder directly over the centre of the part to be fed. The need to stress this important point will be excused. It sometimes happens that local chilling is resorted to at those parts difficult to reach with feeders, but this method unless carefully dealt with will cause weaknesses, particularly in connection with some metals that are likely to become brittle by too quick cooling. Also, metallurgical changes take place under chilling methods, which in many instances are not desirable.

Each class of irons to some extent alters methods of production in respect to feeding and running, on account of alloy and steel additions, which cause increased shrinkage to occur in changing sections, even with very low-phosphorus content. Cast iron is now frequently subjected to quenching and tempering, and much advance also has been made recently in connection with alternative forms as a result of considerable attention by research workers. Much of the advance made in recent years as regards strength of cast iron without alloy additions has been

chiefly due to a reduction in the graphite size, coupled with a reduction in the quantity present.

Lanz "Perlit" Process

The value of obtaining a small amount of graphite in a structurally-fine condition is obvious, as is the desirability of obtaining as high a combined-carbon content as possible in the pearlitic condition. Iron made by the well-known "Lanz Perlit" process is typical. This is obtained by casting into a hot mould iron of such low-silicon content, that it would normally give a white or mottled structure if cast in a mould which was just warm or cold. Moulds made for this class of casting need more careful handling than those for ordinary iron, and feeding methods require more attention.

Figs. 25 and 26 are micrographs of ordinary and Perlit iron, and are in the etched condition, and illustrate the relative amounts of pearlite. Perlit iron, due to the nature of the process, gives a comparatively uniform hardness and structure across the varying sections of a casting, and strengths of 18 to 20 tons per sq. in. tensile may be regularly obtained, together with high resistance to shock.

In order to appreciate fully the great advantage obtained by uniformity of structure in the casting, it should be borne in mind that in castings made from ordinary iron, structures are irregular, the outside portion of the section being more tough than the inside owing to the chilling effect of the mould, whilst at the centre portion of the section, the iron is comparatively open and weak, with large graphite flakes predominating. It is evident, therefore, that ordinary castings having this variation in structure will not give good results in service where resistance to heat and shock is required.

The Perlit-iron process produces a casting which will respond to high duties under elevated temperature conditions, and the contraction stresses are extremely low, due to the fact that the moulds are all heated prior to casting, with the result that the casting cools at a very slow rate. Repeated impact tests have been carried

Fig. 17.—Another Type of Bottom-Half Cylinder Mould.

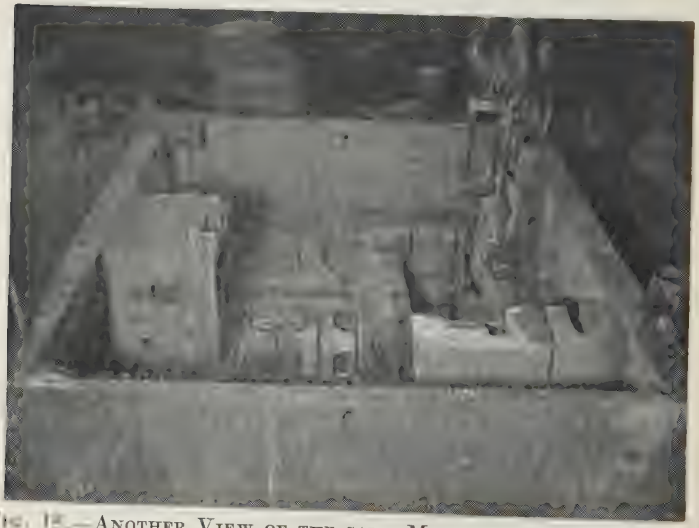


Fig. 18.—Another View of the same Mould showing the First Loose Pieces Inserted.

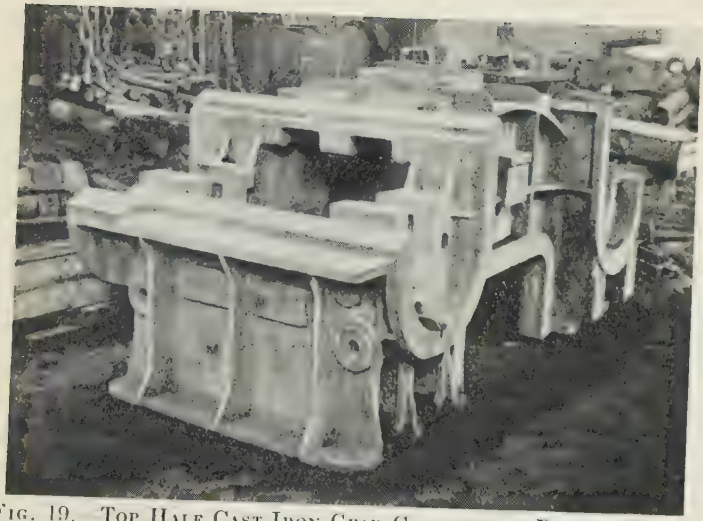


FIG. 19. TOP HALF CAST-IRON GEAR CASE RUN AT BOTTOM FLANGE AS CAST. (Shown in the casting position.)

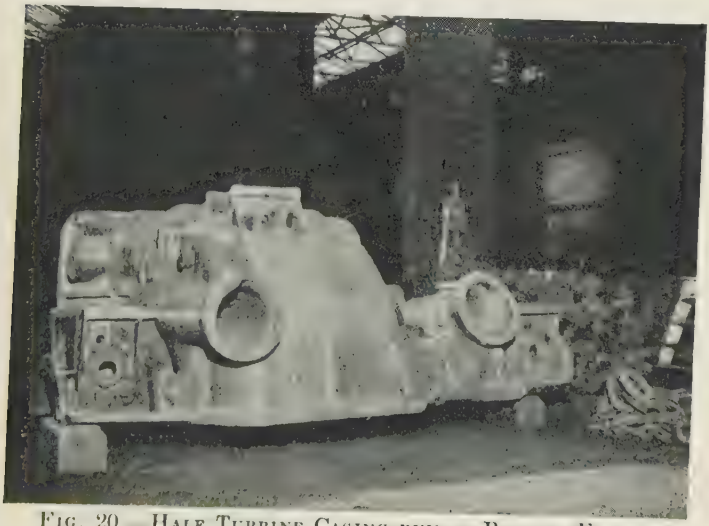


FIG. 20. HALF TURBINE CASING RUN AT BOTTOM FLANGE AS CAST. (Shown in the casting position.)

out, a 28 lbs. weight being allowed to drop a distance of 1 ft. on a sample $1\frac{1}{2}$ in. sq. Samples of Perlit iron tested under these conditions have withstood as many as 382 blows, while samples of ordinary iron, similarly tested, fractured with a maximum of 12 blows. The greater shrinkage is a factor to be allowed for, and the heating of the mould to produce such conditions as will give the required structure necessitates increased attention being given to the moulding sand.

However, providing such conditions are well looked after, castings, such as those shown in Figs. 27, 28 and 29, are successfully manufactured, with analysis as follows:—Total carbon, 3.00; combined carbon, 0.80; and silicon, 0.80 per cent. The large casting to be seen on the left in Fig. 27 was over 5 tons in weight, and was cast at a mould temperature of approximately 320 deg. C. Other irons are made by various methods to produce an extremely-fine graphitic condition, with a corresponding increase in mechanical properties.

Another method already referred to for obtaining improved properties is to heat-treat the metal, and very high mechanical results can be obtained by the process. To obtain the maximum benefit from the material in this form, however, it is necessary to have the combined carbon high, and the graphite should be fine, as coarse graphite materially reduces the value of the improved structure. The results of an investigation recently carried out by the authors on the effect of heat-treating Perlit iron made under the Lanz process are noteworthy.

For the purpose in question, actual castings were taken and cut up for test, so that the mass effect could be taken into account. The results obtained, therefore, indicate the actual strength of the castings, which were cylinder liners for a Diesel engine. The length of these castings was 38 in., the internal dia. 15 in., the section thickness $1\frac{3}{4}$ in. and the average composition was as follows:—T.C., 3.04; G.C., 2.34; C.C., 0.70; Mn, 0.73; Si, 0.76; S, 0.154; and P, 0.133 per cent. After being rough-machined,

the castings were quenched in oil from 850 deg. C. and tempered at temperatures ranging from 450 to 650 deg. C. The most suitable tempering temperature was found to be from 500 to 600 deg. C. as shown in Table I. Had the combined carbon figure been nearer to the ideal of 0.80 to 0.85 per cent. still higher results would have been obtained. Micrographs of such iron are illustrated in Figs. 30A and 30B. Such results should assist designers and engineers considerably, especially where a material of high quality, with graphite present, is required.

TABLE I.—*Mechanical Properties of Heat-treated Perlit Iron.*

	U.T.S. Tons per sq. in.	Transverse test 1 in. sq., 12 in. cntr.			Brinell No.
		Tons.	Defn. in in.	Modulus of rupture. Tons per sq. in.	
Original iron	16.4	1.75	0.375	31.5	179
Quenched 850 deg. Tempered 500 deg.	26.8	2.75	0.28	49.6	303
Quenched 850 deg. Tempered 600 deg.	26.0	2.50	0.31	44.9	263

Alloyed Cast Iron

Another well-known method of obtaining enhanced properties is by means of alloy addition, usually nickel and chromium. Such improvements, however, are noticeable, not so much from the point of view of high mechanical strength as from the greater equality of structure obtained across varying sections, giving greater uniformity and therefore more reliability in service.

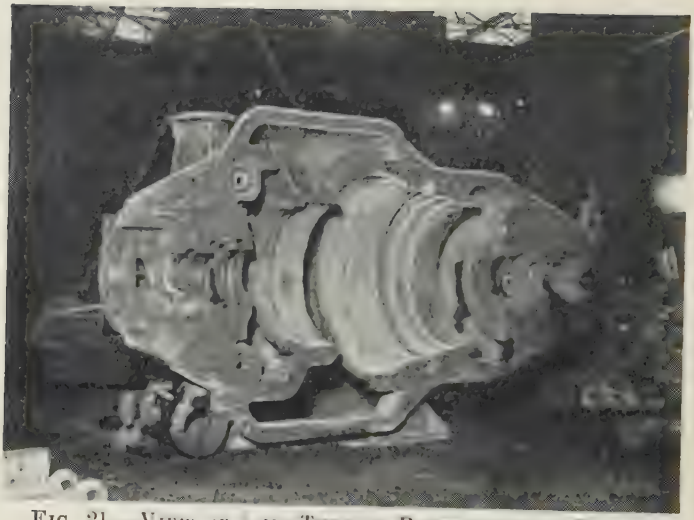


FIG. 21.—VIEW OF SAME TURBINE PIECE SHOWING CORED PORTION.

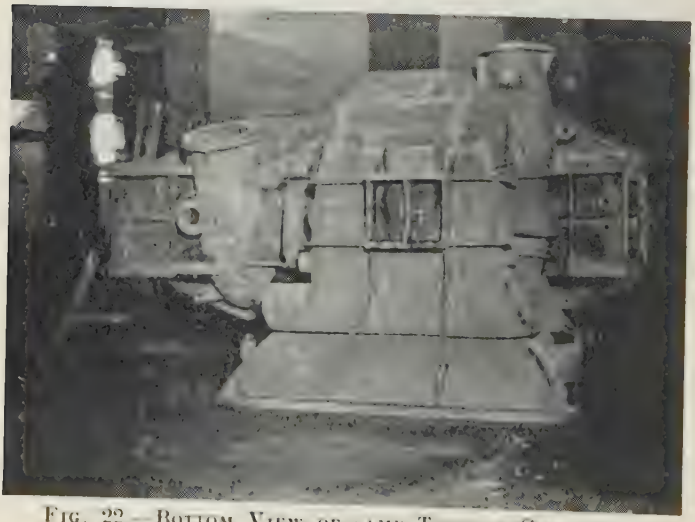


FIG. 22.—BOTTOM VIEW OF SAME TURBINE CASTING.

Much progress has also been made in relation to materials for specialised applications, such as resistance to heat and corrosion. Regarding the former, ordinary cast iron fails at high temperatures as a result of rather complicated reaction.

In addition to surface oxidation, there are decomposition of the cementite present into ferrite and graphite, and expansion due to volume changes of the micro-constituents, and further oxidation along the fissures produced.

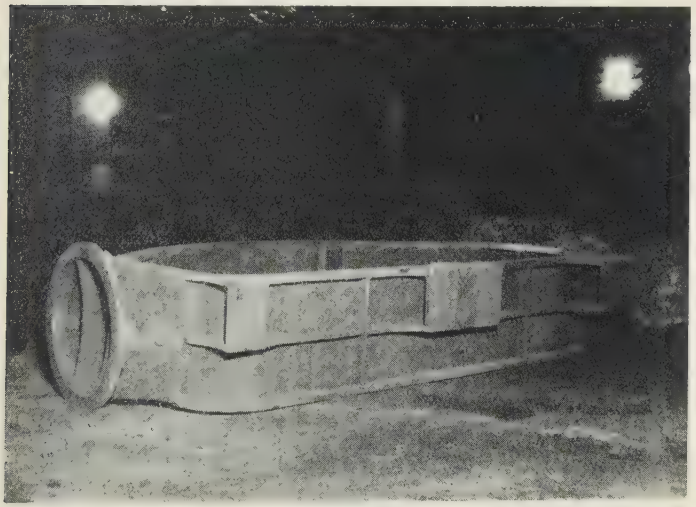


Fig. 23.—Condenser End Casting.
(Shown in casting position.)

Oxidation takes place to an increasing extent on ordinary iron with increased silicon content, but it was discovered that if the silicon content was taken well above the ordinary range, viz., from 6 to 7 per cent., very good heat-resistance properties were conferred. For temperatures up to about 850 deg. C. this material gives very good service and is known as "Silal." Lanz Perlit iron with low-silicon content also has very much less growth than ordinary engineering irons, and this iron gives excellent results when subjected to

elevated temperatures. For higher-temperature service, however, austenitic iron such as Nicrosilal, gives almost complete resistance up to approximately 1,050 deg. C.

Table II gives the figures of some work recently done by the authors in this connection, giving

TABLE II.—*Repeated Heat Tests to 950 deg. C. of Various Irons.*

Material.	Percentage change in	
	Volume.	Weight.
Ordinary iron	+70.1	+21.0
Silal	+ 4.5	+ 0.3
Nicrosilal (hard)	+ 0.4	— 0.3

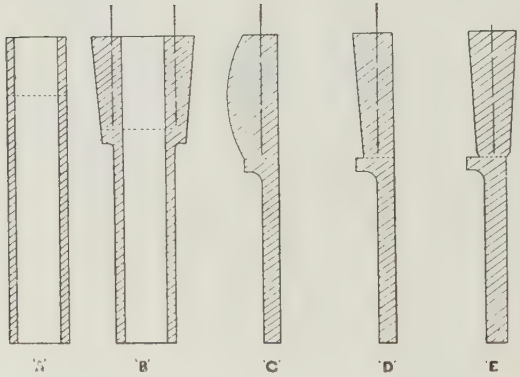


FIG. 24.—VARIOUS TYPES OF FEEDERS USED ON CAST-IRON LINERS AND OTHER CASTINGS OF A CYLINDRICAL TYPE.

the results of dimensional and weight changes after treatment of ordinary engineering iron, 6 per cent. silicon iron (Silal) and austenitic iron (Nicrosilal), after ten heatings to 950 deg. C. in an oxidising atmosphere, alternating with cooling down to atmospheric temperature. Nicrosilal contains 6 to 7 per cent. silicon, 18 per cent. nickel and 2 and

5 per cent. chromium respectively, in the soft and hard qualities. Fig. 31 shows the appearance of specimens after the test just described. The structure of this iron in the hard variety is shown in Fig. 31A.

The casting properties of these alloys are good, but contraction is more than that of ordinary cast iron, and therefore it is necessary to take special precautions during the manufacture of moulds, so that contraction is not retarded in

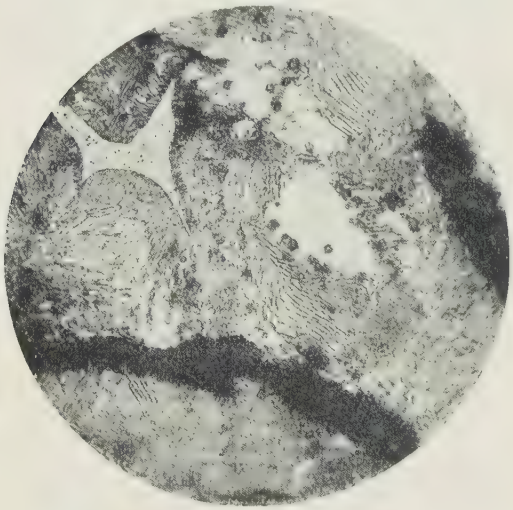


FIG. 25.—ORDINARY IRON ETCHED. × 400.

any way, otherwise hot tears occur. A casting is shown in Fig. 32 made in soft Nicrosilal, this piece being 10 ft. long, 3 ft. 6 in. wide, ½ in. thick. It will be appreciated, therefore, that the metal is sufficiently fluid to cast complicated pieces.

The Non-ferrous Castings

Referring now to non-ferrous materials, a type of casting in connection with which considerable difficulty has been experienced is the liner for use on propeller shafting, made in gun-metal

(88 copper, 10 tin, 2 per cent. zinc), known as Admiralty quality. These castings are machined all over, and have to withstand water pressure without showing signs of leakage. Many foundrymen would not hesitate one moment in casting these in a vertical position; it is known that many are made to-day under that method, in fact, specifications mention in some cases that they must be cast vertical.

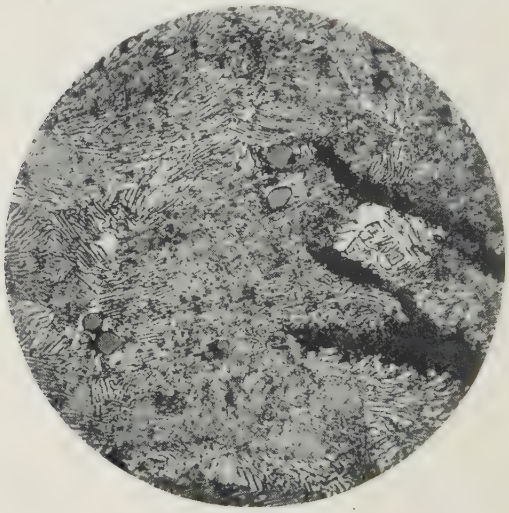


Fig. 26.—Perlit Iron Etched. × 400.

The results, however, have not been at all good, the main defect being unevenness due to cooling, causing irregular contraction and varying grain size, though the casting thickness is regular throughout. The best casting method has been found to be horizontal, not vertical, and its construction is shown in Figs. 33 to 38.

The runner basin is shown in Fig. 35 ready to receive 5½ tons of metal. The mould in this instance is set carefully by the aid of a spirit level, it being essential that the metal should rise evenly over the whole length of the job

during casting. The runners are all plugged with lift plugs, the intention being to pour the whole of the metal into the basin before any is released into the mould. When the metal is poured, all runner plugs are drawn simultaneously, and the mould very quickly filled, with the result that there is an even temperature

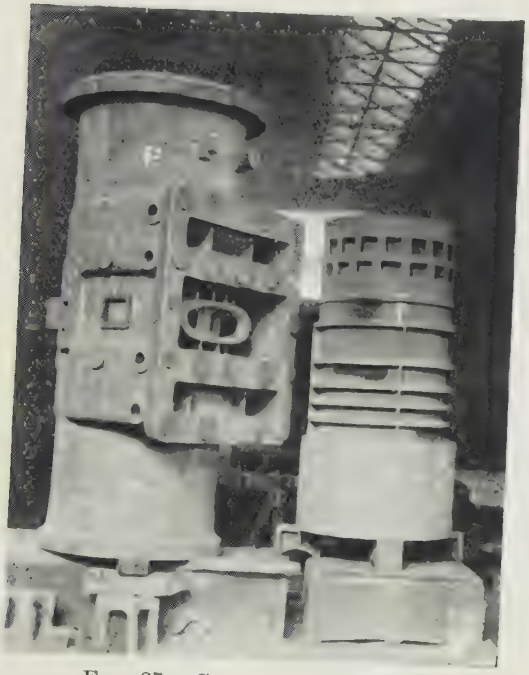


Fig. 27.—Castings in Perlit.

existing throughout the entire mass of metal in the mould.

It is obvious that the whole length of the casting will be at the same temperature and contraction will commence and continue evenly all over as it should do. The contraction on this casting was 4 in., *i.e.*, the actual casting was

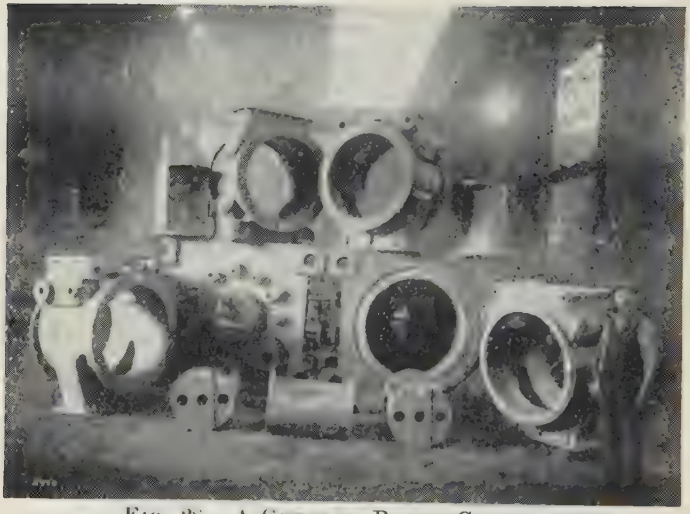


FIG. 28.—A GROUP OF PERLIT CASTINGS.

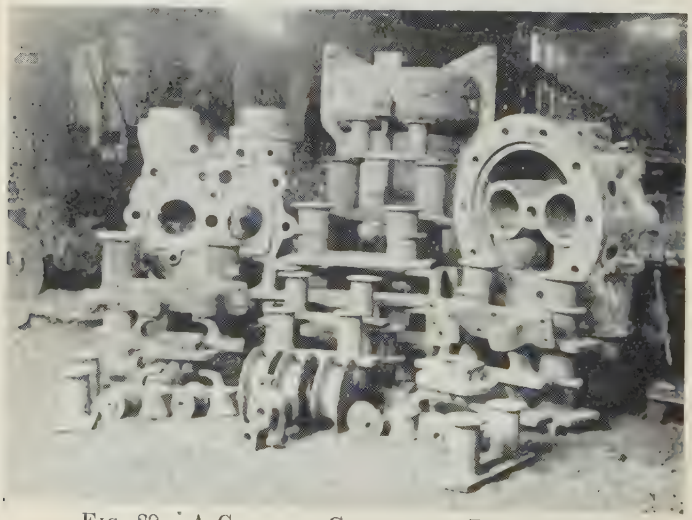


FIG. 29.—A GROUP OF CASTINGS IN PERLIT IRON.

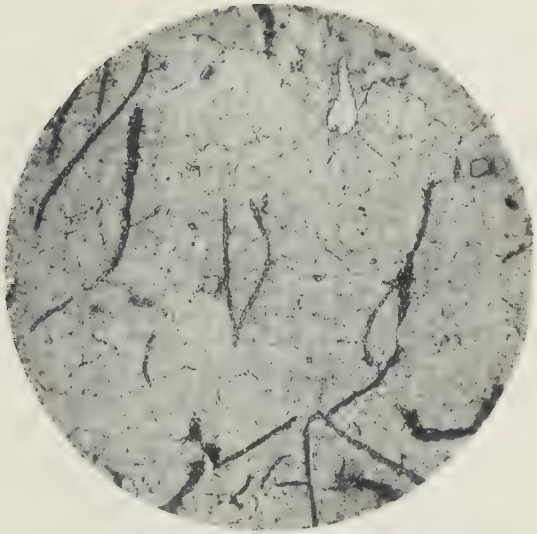


FIG. 30A.—HEAT-TREATED IRON. × 100.

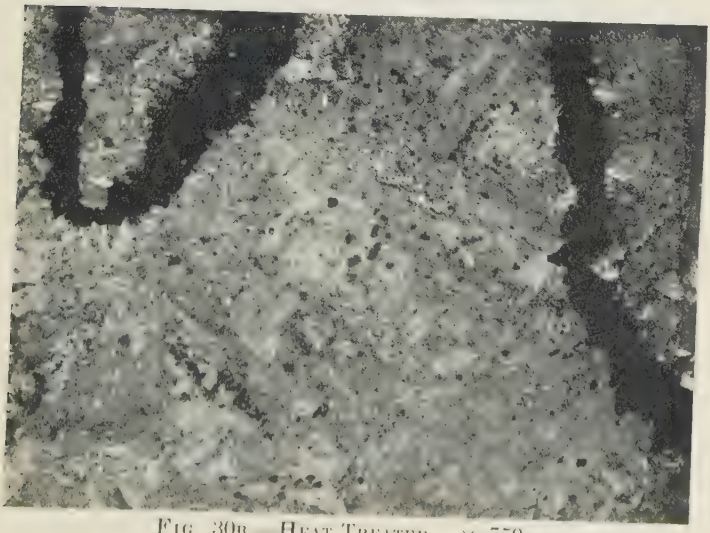


FIG. 30B.—HEAT-TREATED. × 750.

4 in. shorter in length when cold than the mould was before casting. It is obvious then that the more even one can keep the temperature throughout the whole length of the casting, the more even contraction that will be obtained. It will be appreciated that any drag that may occur, due to uneven contraction, will cause the metal to tear, and if cracks are not seen by the naked eye it is certain that the grain will be disturbed.

Manganese Bronze

Another alloy extensively used by engineers, for many important applications, is manganese bronze or brass. There is a large variety of these alloys in use, differing in composition with the ultimate tensile strengths varying from 28 to 50 tons, with from 12 to 30 tons yield, and 12 to 35 per cent. elongation in the cast condition. These alloys are much more difficult to cast than gun-metal, the shrinkage being very much more pronounced.

The methods of feeding, therefore, are very similar to those for steel, and unless large feeding heads, or local external chills, are used over changing and thick sections, good results in the finished castings cannot be obtained. The use of chills is not considered advisable, except in instances where feeders cannot be effectively used. The method of running is very different from that of steel, owing to the rapid oxidation of the metal due to the high zinc content. It has been found in practice that when casting these alloys the runner should contain a series of skim bridges to clean away the oxide and to prevent its entry into the mould. The distribution of the runners is another important point, practice again proving that equal cooling of the casting gives the more satisfactory results. The correct method, therefore, is that of fixing the inlets into the mould in such a manner that equal cooling of the casting is assured.

The thicknesses in the casting shown in Fig. 41 vary from $\frac{1}{2}$ in. up to 2 in. These are extremely complicated pieces, and it is necessary

that great care be used in the making of mould and core. The core (Fig. 39) is made on flimsy lines so as not to retard contraction, the core irons and sand being kept as weak as possible. Fig. 40 shows the core assembled in the mould with the top part in view showing the position and size of feeders used, together with the two runners, one at each end to maintain an even

Fig. 31.—Appearance of Samples after Heat Testing.

cooling rate. The runner carries a skim bridge at the bottom. It will be observed how different are the methods required in the running and feeding of each class of metal, and also the variation in the disposition of the feeders.

In the making of moulds and cores, some are reinforced with heavy irons, others are insufficiently vented, whilst others, again, may be badly rammed or packed. Such conditions as

FIG. 31A.—STRUCTURE OF HARD NICROSILAL IRON × 250.

FIG. 32.—CASTING MADE IN NICROSILAL.

Fig. 33.—Mould for a Gun-metal Liner 21 ft. 3 in. in Length.

Fig. 34.—Core in Position.

these are obviously opposed to the obtaining of quality in the finished product. The various operations in the building of either unit, if incorrectly carried out, are almost certain to produce defective castings.

To illustrate the importance of the mould or core being made on lines just sufficient to with-

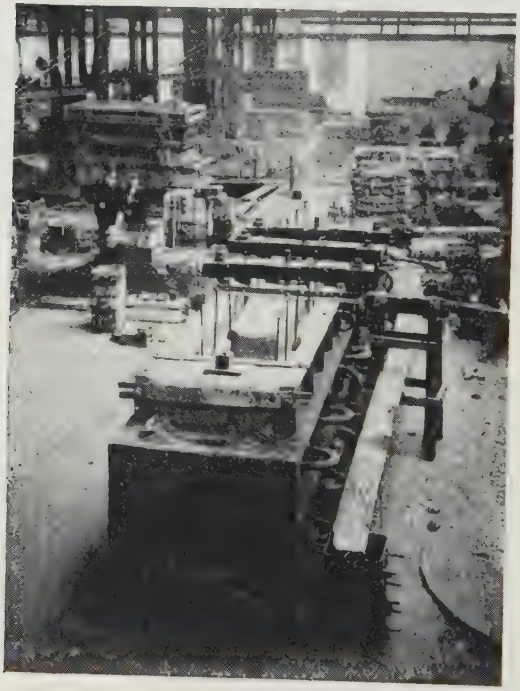


FIG. 35.—THE COMPLETED MOULD.

stand the pressure and wash of molten metal and not to hinder contraction, Fig. 42 shows the contraction allowances on 8 ft. of steel, brass and iron. In Fig. 43 contraction fins are shown to have been added to tie the changing sections together; also, the moulding box is put together in sections for quick dismantling. The sand in

this mould for turbine castings is no more than $2\frac{1}{2}$ in. thick in any part, all the backing material being of cinder, which crushes during the contraction of the casting.

Propeller-Shaft Bracket.—The thickness of the boss of the casting, the pattern for which is shown in Fig. 44, is 10 in. in places, and at the box end 2 in. to 8 in. It is important that the mould be made so that the part in front of the box, or between the boss and the box, is weak. The weak part is shown where the peg projects through the joint (Fig. 45). The mould on each side at this position is removed quickly during the easing operation so as to allow this portion of the casting to move towards the boss. This is necessary as a result of that part of the casting solidifying much quicker than the boss, which, as stated, is of thicker section. The box is formed with three drawback pieces, instead of one, to facilitate ease of contraction as is shown in Fig. 46. Feeders are used to feed the boss—the top half of the mould is made in two pieces. Fins are added to assist in preventing hot tears during the contraction period, and, also, to tie the changing sections together. These fins are made less than the thinnest portion of the casting, so that they solidify quicker than those parts and give the necessary assistance.

The mould was dried by means of portable hot-air stoves and the temperature taken at five points in the mould after two days ranged from 280 to 320 deg. C. This system of drying moulds is excellent on many classes of work, but some other large moulds of a shallow type are found to be better dried by other means.

Stern Frame Casting.—Figs. 52 *et seq.* show the importance of mould construction in connection with the correct building-up of all loose pieces to give the right thicknesses.

In Figs. 53 and 54 is shown the upper part of the mould with a drawback on the joint before insertion into the mould. In Figs. 55 and 56 are shown the completed castings after being fitted together.

Cast-Steel Rudder Frame.—Figs. 57 *et seq.* show the complete manufacture of a mould for a

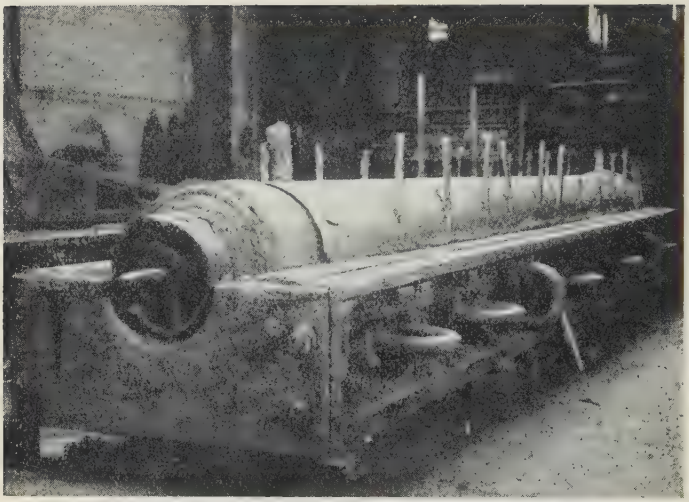


Fig. 36.—The Top Part of the Mould Stripped from the Casting, Illustrating the Even Spacing of the Runners.

Fig. 37.—Close-up View of One End of Liner.
(Note the divided contraction of 2 in.)

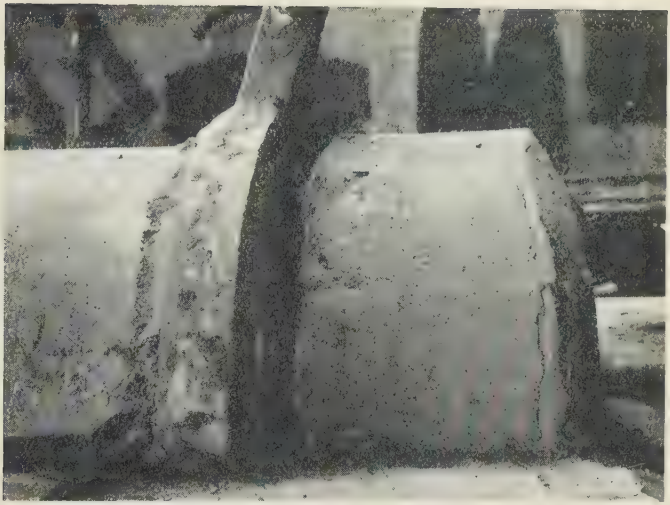


FIG. 38.—THE OTHER END OF LINER.
(Again note the divided contraction of 2 in.)

FIG. 39.—CORE FOR PERISCOPE SECTION IN MANGANESE BRONZE.

cast-steel rudder frame, and indicate the piecemeal building up of the various parts which go to make up the complete mould. The feeders are arranged at positions—1, 2, 3, 4 and 5 (Fig. 57) —and each is of sufficient capacity to permit ample feed of molten metal down each leg of the casting. There is no declivity in the casting position owing to the irregular thicknesses occurring in the design, which occur at the numbered positions. The bottom of the mould, it will be noticed, has been packed, and the joints around the pattern are being made, in preparation for the building of the sides of the mould.

The joints for the drawbacks in between the arms are carried below the pattern in order not to interfere with free movement of the arms to the main body of the casting during contraction. The estimated finished weight of the casting was 13½ tons. The allowances that have to be made for the feeding of castings of this description are about twice the finished weight to cast, and in this particular instance 23 tons of metal were used. The drawbacks are made in hollow form to obtain quick easing during the contraction period. One of the pieces of pattern in Fig. 58 has been removed, showing details of pattern construction, permitting the drawbacks to be made flimsily of loose irons and cinder material. Cast-iron grids would be too rigid to use in these drawbacks, and would reinforce the mould, thus hindering contraction. In Fig. 59 one of the drawback plates is ready for insertion, with others about one-half constructed.

The responsibility of the moulding operations is given to one of the best craftsmen, who can be seen in Fig. 59 between the two chains, setting his last drawback plate in position, with the remainder of the squad engaged on the other drawbacks. There is no crowding of workmen at any point, each member being busily engaged on different parts of the mould. The work, therefore, proceeds evenly as directed, by the assignment of duties to each member of the squad in

connection with which supervision plays a most important part.

The upper half (Fig. 60) is in six separate pieces, in order to be able to strip it in sections, at periods of solidification determined by the varying thicknesses. A joint is used between each of the top parts which leaves gaps $\frac{3}{4}$ in. wide, and these are made up with sand after the mould is completely assembled. The construction of the top parts of the mould is by means of loose iron grids, the sand between which is reinforced by small pieces of soft bar iron bent and hooked on to the grids. This assists the lift of sand weight, giving the correct profile of the top half of the mould. One of the joints in the top half of the mould is shown, in Fig. 61, ready to receive other top parts, whilst another is being completed by three of the moulders on the right of the illustration.

Some of the feeders can be seen projecting through the grids, the clearance in which must be sufficient to give a thickness of sand to allow easy removal after casting. The grids are made under the supervision of the chargehand, a day of two before they are required, to the templates seen in the background of Fig. 62, to dimensions taken during various stages of manufacture of the mould. The top parts are shown completed, in Fig. 63, with the exception of the large centre part, which contains the main feeders or headers. It will be noted that all the small top parts may be removed before this large top part.

The manufacture of the top part on the lines indicated enables it to be removed in pieces, and allows the arms of the casting to contract freely as they solidify prior to the heavy sections being set. In this particular job the arms of the casting were black, whilst the main body under the large top parts was in liquid condition. It will be appreciated, therefore, how important is mould construction to facilitate contraction of the various thin parts in accordance with the varied rates of cooling.

FIG. 40.—MOULD FOR PERISCOPE SECTION IN MANGANESE BRONZE CASTING.

FIG. 41.—THE CASTING, WITH RUNNERS AND FEEDERS ATTACHED.

One of the small top parts being taken off is shown in Fig. 64. The various loose parts of the mould are each marked before being removed, enabling the moulder to put each part back into the same position when the mould is reassembled after being dried. Some of the marks can be seen around the edges of the top piece. All the small top parts have been lifted off and the large top part with feeders or headers is shown being removed in Fig. 65. The screwed

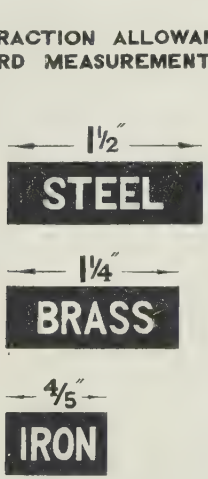


Fig. 42.—Steel, Brass and Iron Contraction on 8-ft. Lengths.

links in the lifting tackle allow parts of the mould to be moved in an angular direction, which permits the removal of those loose parts that go to make the completed mould, without any serious breakage of sand, thus retaining pattern profile in the entire mould when completed. In Fig. 66 it will be noticed that all drawbacks have been removed with the exception of the one on the left, where preparations are being made to remove it.

The last drawback having been taken out, operations can now proceed for removal of the pattern. The overhang of sand from the drawback plate is carried with loose irons instead of, in many cases, cast-iron grids.

The removal of the first piece of pattern was, as

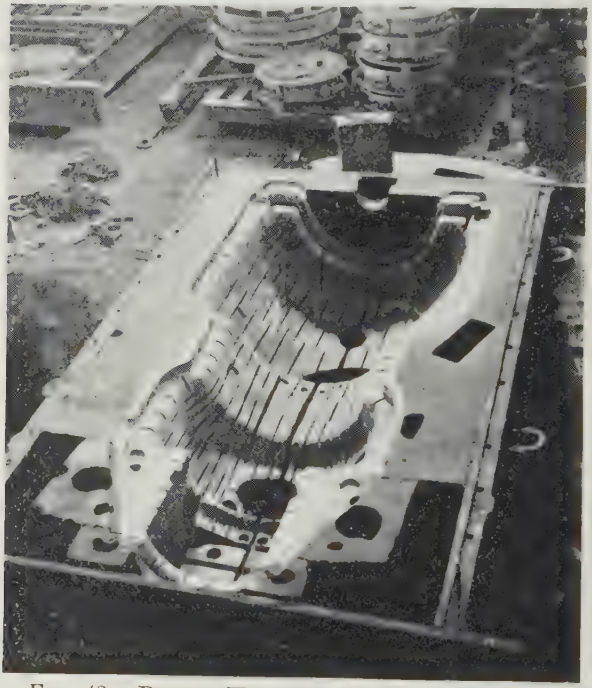


Fig. 43.—Bottom-Half Mould for a Cast-Steel H.P.-Turbine Casting.

is shown in Fig. 67, carried out with ease, illustrating the importance of pattern construction in accordance with foundry requirement. The withdrawal of the other main piece of pattern (Fig. 68) completes the strip of the mould, which is now ready for finishing, preparatory to being dried.

Fig. 44.—Pattern of Steel Propeller-Shaft Bracket set in Casting Position.

Fig. 45.—Joint being made.

Fig. 16.—Another Stage of Operations on the Mould for the Propeller-Shaft Bracket.

Fig. 17.—Top Parts being Constructed.

Fig. 48.—Finishing the Mould.

Fig. 49.—Finishing the Bracket Mould.

The bottom half, all in one piece, and all the various pieces comprising the complete mould are shown in Fig. 69. The method of construction of the bottom half has been carried out so as to enable drying operations to be undertaken effectively. After the mould has been dried, it is an easy matter to leave the fire at various parts of the mould and so retain warmth whilst the moulders continue working on the closing operations.

Fig. 71 shows that closing has actually commenced at one side, from where the fire has been removed to another section. The modern hot-air drier is not a very convenient unit to use on a job of this description, on account of the area being so large and the mould so shallow. It will be appreciated that on a large complicated job of this description five or six days are required to complete the operation of closing, during which period the mould would be cold, were not such a method employed as described for retaining the heat.

All the drawbacks are shown completely assembled in Fig. 72, as well as the contraction brackets added to the mould to tie together the heavy and light sections. The extreme thickness of some portions of the casting will be apparent, as demonstrated by the moulder seen trying the thickness under one of the drawbacks. He is actually standing in one of these portions of the mould doing his work. It will be of interest to note the hollow form of the drawbacks, which considerably assists in their removal during the easing stage.

The main top part is shown being put into position with feeders added in Fig. 73, all of which have been completed and the height added, to meet the amount of thickness to be fed in the casting. The hollow forms of the drawbacks are shown to be very flimsily built to allow of easy removal.

Once again a large number of feeders are used. In Fig. 75, one of the moulders can be seen descending the feeder to examine the mould, and to make certain that the joints of the top

parts and drawbacks are lineable with the main body of the mould. Weights are used around the outside of the mould to pack to the pit sides instead of ramming up the pit with a great bulk of sand. This procedure enables the pit to be quickly stripped to allow the various pieces of the mould to be expeditiously removed when the easing operations begin. The process of removing the pieces of mould at the correct time is important, as any part of the casting held by ledges or projections in the mould, or cores, brings about the danger of contraction cracks, or hot tears.

The two ladles of molten steel are shown in position over the mould just prior to the commencement of the casting operation in Fig. 77. The larger ladle contains 21 tons of metal and the smaller one 2 tons. Two ladles are used in order to obtain quick filling of the mould, and to ensure all thin sections and fine edges being completely cast. The wooden rods shown are used to keep the ladles steady during the casting operation, and to prevent spilling of metal over the sides of the runner basins. The mould was poured in 9 min., equalling 1 ton every 24 sec. Ten tons of metal were poured from the large ladle before the metal in the small ladle was released.

The two tons of metal in the small ladle, stationed at the point furthest away from the large ladle, heat up the surface of the metal at that part, giving a sharp cast result around the top of the casting. The metal in the larger ladle was produced from the Siemens open-hearth furnace and that in the smaller one from the Tropenas side-blown converter. The analysis of the metal in each ladle was the same within very fine limits.

Large castings, such as the one now being described, are more efficiently produced by means of two melting plants, thus enabling the mould to be run from more than one position. It is always useful, where large castings are made, to have a smaller type of plant available, as, if required, a further quantity of metal can be

Fig. 50. Another View of the Work of Finishing.

Fig. 51.—The Mould being Dried by means of Hot-Air Dryers.

Fig. 52.—Mould for Piece of Cast-Steel Stern Frame.

Fig. 53.—Upper Part of the Mould for a Stern Casting.

obtained for feeding purposes, after considerable shrinkage has occurred, some time after the mould has been cast.

The time of commencement of pouring is important, and is determined by the periods required for cooling the varying thicknesses of the casting. Prior to casting, the points at which easing will commence have been discussed, enabling the foreman to instruct the skilled and unskilled workmen accordingly.

The removal of the small top parts over the arms commenced about three-quarters of an hour after casting the job (Fig. 78), and it is interesting at this stage to note that the temperature at the end of the arms, at the finishing of the easing operations, was 250 deg. C., whilst that of the main body was above 850 deg. C. Two hours after casting, all the top parts and drawback plates had been removed, allowing the light parts of the casting to move freely towards the heavier portions. The casting is allowed to cool to shop temperature, being removed from the pit after about five days. The feeders numbered 1, 2, 3, 4 and 5 in Fig. 79, used for feeding the heavy sections referred to, can now be plainly seen. They are noticeable over the main stock of the rudder casting, and opposite each arm.

After the casting has cooled down to shop temperature, it is rough-dressed, and removed from the pit into the annealing furnace, where it is carefully supported all around, in order to retain its true shape during the annealing process. The annealing furnace is 30 ft. long, 25 ft. wide and 12 ft. high, totally enclosing the casting and giving uniform heating. The gas is supplied from a producer specially installed, with ports arranged so that the gas may be shut down at any part of the casting which may be getting too hot, and transferred to those parts requiring more heat, thus getting an even rising temperature. The annealing temperature is 900 deg. C. and the soaking period for a casting of this description is approximately 48 hrs. This casting was in the annealing furnace for one week.

The annealing of steel castings has a twofold purpose, viz., to refine the structure which,

after casting, is coarse, angular, and consequently brittle (Figs. 81 and 82), also to relieve stresses following cooling in the mould of the irregular-shaped masses in the design. These objects are attained by heating to a temperature above the upper critical point of the steel, usually from 850 to 900 deg. C., according to the carbon content in the case of both medium- and low-carbon steel, soaking for a time, depending upon the weight and sections of the casting, and subsequently cooling down slowly to produce the desired structure and freedom from contraction strains. With higher carbon steels and alloy steels, consideration must be given to the different temperatures which may be employed, as they are derived from the upper critical points of the materials in question.

Other important points are that the furnace, when charging the castings, should be cold, and the castings slowly heated so that thick and thin sections in the design are uniformly heated to avoid expansion stresses. As long a period as 9 hrs. may be required to heat, and 18 hrs. or even more to soak such a casting as, say, a steam chest weighing 2 tons. This would take approximately 24 hrs. to cool down Overhanging masses of metal require support, as, at the annealing temperature the metal is in a weak condition and distortion may occur.

The furnace gas ports also should be of such design that the flames do not directly impinge on any part of the casting. In addition, a large number of gas ports is desirable so that the gas may be regulated to meet heavy- and light-section thicknesses. Difficulties often arise with large castings in attaining a uniform temperature, and this can only be obtained by careful control in an annealing furnace of good design.

For important castings it may be desirable to take the temperature at different points, and this is done by attaching long thermocouples to various parts of the castings after positioning in the furnace, the thermocouples being led through holes in the furnace door and walls. Temperatures are taken at the various points by using a pyrometer indicator, and by this means

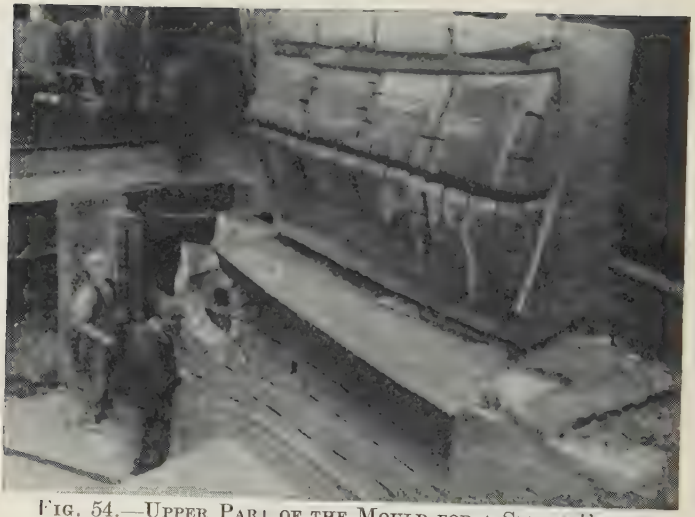


FIG. 54.—UPPER PART OF THE MOULD FOR A STERN FRAME CASTING.

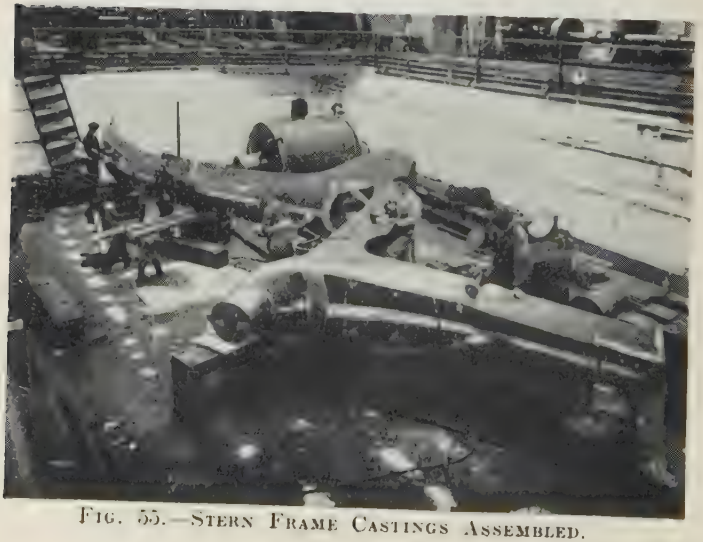


FIG. 55.—STERN FRAME CASTINGS ASSEMBLED.

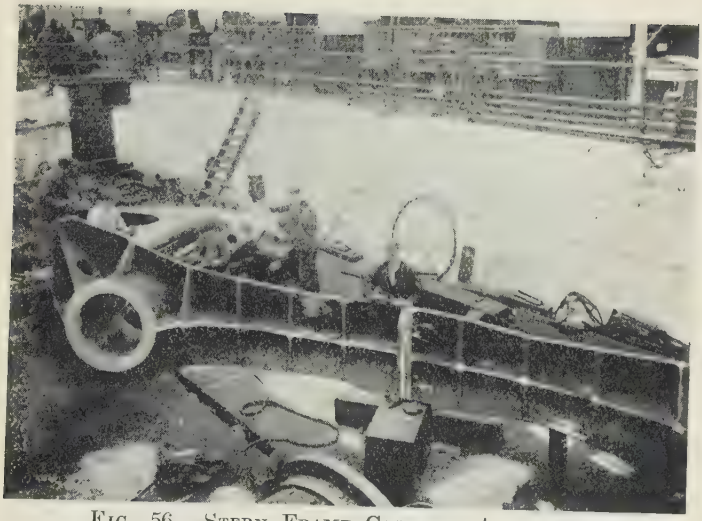


FIG. 56.—STERN FRAME CASTINGS ASSEMBLED.

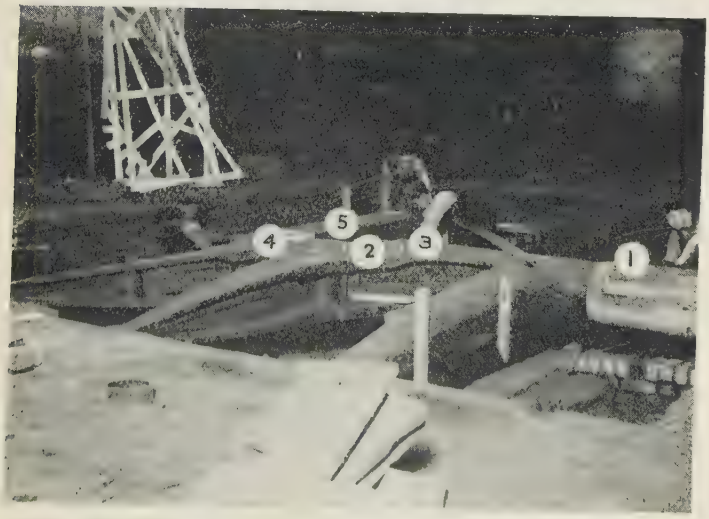


FIG. 57. PATTERN SET IN POSITION AND RAMMED UNDER.

the rate of heating can be adjusted to give a uniform temperature rise.

In the case of castings for high-temperature and high-pressure service, residual strains, which may be present after rough machining, are removed by a further heat-treatment. In these cases the castings are heated again to 650 deg. C., the heating time being 5 hrs., soaked for 3 hrs. and cooled slowly during a period approximating 12 hrs. A method of annealing also advocated is to heat to the upper point, cool slowly to a temperature below the lower critical point, say 600 deg. C., re-heat to a little above the lower critical point, say 750 deg. C., and then slowly cool. More complicated forms of heat-treatment, as by quenching and tempering, are also employed.

It is not generally realised that steel castings can be materially improved by such treatment, but great attention has been given to this point recently, especially on castings required for high-duty service. Steel castings produced in the authors' works, weighing several tons, have been successfully quenched and tempered, the following being figures obtained from steel containing 0.30 per cent. carbon and 0.50 per cent. molybdenum:—*Annealed.*—Yield point, 21.0 tons per sq. in.; U.T.S., 34.0 tons per sq. in.; Elongation on 2 in., 23 per cent.; and Brinell hardness, 143. *Quenched and Tempered.*—34.0 tons, yield point, 47.2 tons U.T.S., 17 per cent. elongation and 269 Brinell hardness. The increase in mechanical properties is, it will be appreciated, very marked.

These figures, although good, do not indicate the real value of such material, the most noticeable improvement over straight carbon steels being the creep-limit properties at high temperatures. Such properties are of the utmost importance for castings working under high-pressure conditions at elevated temperatures, as it is important that the castings maintain their true shape. The microstructures of the material as annealed and heat-treated (quenched in oil

from 900 deg. C., tempered from 600 deg. C.) are illustrated in Figs. 83, 84 and 85.

Manufacture of Rudder Casting (continued).—When the dressing is completed and the material satisfactorily tested and inspected by the overseer, the feeders are cut off by the oxy-acetylene process or by cold saws of the circular or band type. The casting is lined up by the loftsman, and, happily, this particular casting was found to be correct without any setting having to be done. It sometimes happens that a casting is twisted or out of shape, due to the contraction being uneven as a result of local hot parts. In such cases the casting is again set up in the annealing furnace and the twist adjusted. The casting is then turned and bored prior to despatch to the ship department for packing and plating. The machine shown in Fig. 86 is a wall plate, the cutter travelling along the full length of the stock portion of the casting. The placing to the ship of such a casting is not an easy operation, owing to the irregular shapes and weights, and the small working clearances.

The lines of the cast-steel stern frame can also be prominently seen, and the gudgeon, which is part of that casting, forms the hinge on which the rudder swings.

The illustration Fig. 88 shows the contour of a modern design of stern frame, the scantling thickness being as low as $\frac{3}{4}$ in. in places. The length of one of these pieces is over 33 ft., the contraction on this length being over 6 in. One of the cast-steel shaft brackets can also be seen in Fig. 87 forward of the rudder. It will be appreciated that throughout the various phases of mould manufacture, as illustrated and referred to, a high degree of craftsmanship is exercised.

Moulding by Strickleboards.—The mould shown in Figs. 89, 90 and 91 is built up to design, much as a bricklayer would build a wall, being faced up with a thickness of loam or refractory mortar, by means of which a true-shaped casting can be produced.

FIG. 58. BUILDING UP THE DRAWBACKS.

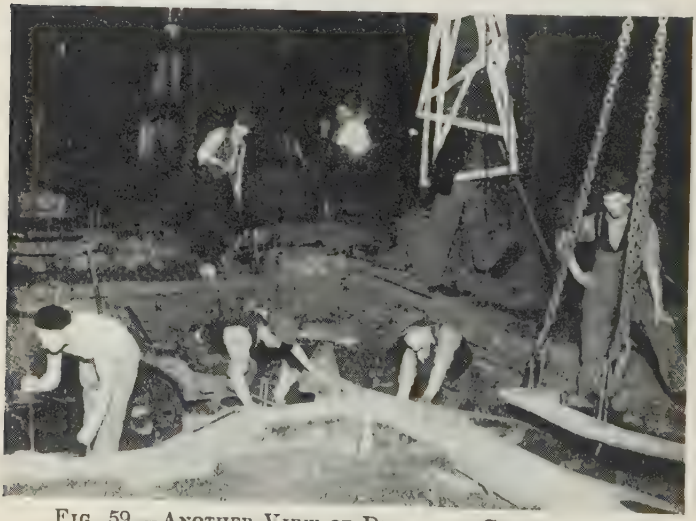


FIG. 59.—ANOTHER VIEW OF DRAWBACK CONSTRUCTION.

FIG. 60.—COMPLETION OF DRAWBACKS AND JOINT MADE AROUND THE PATTERN IN READINESS FOR COMMENCING THE UPPER HALF OF THE MOULD.

FIG. 61. CONSTRUCTION OF TOP PARTS OF MOULD. P 2

Coremaking

The greatest care is necessary to ensure that cores are manufactured so as to offer a minimum of resistance to the contraction of the metal, and this is of the greatest importance in the production of steel castings. It is a simple matter to produce a core reinforced with a large cast-iron grid, and the core made in this manner may appear to be all that is desired from the point of view of symmetry, but it will probably be useless so far as the production of a sound casting is concerned.

In the cores required for turbine and pressure work, experience shows that they must be built in a manner just sufficiently strong to hold together, to withstand the wash of molten metal and resist the pressure in the mould during casting. Such cores are essential for the manufacture of steel castings, and are built up of loose irons of just sufficient thickness to do the job, tied together in the form of a cage, as shown in Figs. 92 and 93. These irons, being loose, offer no resistance to the crushing of the core during contraction, bending easily when heat is transmitted to them from the metal, immediately the mould is poured. Comparatively slight thicknesses of sand are used, which, heating up and becoming soft, act similarly. This inner part of the core can be made with a mass of cinder material, which crushes when the walls of the core are subjected to the pressure of contraction.

Cores are also manufactured in various oil-bonded sands without using core irons, but it is doubtful whether such are suitable for many types of castings owing to their resistance to contraction. Oil sand has many applications, but should be used with careful judgment, or a stronger core may be produced than even that in which cast-iron grids are enclosed.

The large core shown in Fig. 94 was made with loose irons, cinder material and a 2-in. thick wall of sand on the surface. It was reinforced with a loose iron cage of a thickness and strength just sufficient to carry the core to its position in

the mould. Cores of this description have frequently been made above 12 ft. in length, approximating 4 ft. in diameter, the object being to obtain a weak core which would not offer any resistance to the contraction of the casting.

The large cast-steel wheel shown in Fig. 95 is over 16 ft. dia., contraction over 3 in., which means the casting is 3 in. smaller when cold than the mould. It will be appreciated that cast-iron grids used in cores which are fitted close to the inside of this casting would retard the contraction and probably cause serious hot tears. If the wheel were made in cast iron under such conditions, serious contraction strains in the arms of the casting may cause trouble in service on account of such castings not being annealed to remove the strains.

The manufacture of a large core, such as is shown in Fig. 96, where very heavy sections of metal exist, is in come cases carried out with a cast-iron grid embodied, but the grid is kept small, and is only used to fasten the two halves of the core together, and to convey it into position in the mould, the remainder of the core being built with loose irons. The grid will be noted in the centre.

The loose iron cage which carries the three external belts of cores is assembled by means of other irons fastened horizontally with the core-box, these being seen in the corebox. The whole of the cage is then attached to the cast-iron grid, therefore the core iron is not as rigid as would have been the case had they been cast on to the grid and run right into these projections. As is shown by Fig. 97, the whole of the weight is being taken by the grids, the two pieces having been fastened together to make the complete core.

The type of grid used in the manufacture of this core can be freely broken through its centre after casting, the whole of the loose irons are then free to move, and having been heated up by the temperature from the metal being transmitted to them, they easily give way when the

Fig. 62.—Construction of Top Parts of Mould.

Fig. 63. Construction of Top Parts of Mould.

FIG. 64.—THE SQUAD COMMENCING TO STRIP THE MOULD.

FIG. 65.—LARGE TOP PART BEING STRIPPED.

contraction commences to press against the surface of the core. It will be appreciated that the manufacture of cores on the lines indicated is very highly-skilled work carried out by clever craftsmen, and experience is necessary before such work can be satisfactorily accomplished.

Supervision of the highest degree is essential to ensure that the points outlined are carefully and accurately observed, otherwise those results necessary to meet inspection and specificational requirements will not prevail. Cores required for castings in iron and practically all the non-ferrous alloys, are not so vitally important from this viewpoint of contraction, and therefore oil sand may be used more extensively; also greater risks may be taken in instances where core irons are used without oil sand. On the other hand, even in these cases, cores that are made on as weak lines as possible give better results, ensuring less contraction strain in the casting when it reaches normal temperature.

It must be appreciated that if contraction in iron and brass is not normally obtained, stresses will exist in the finished casting, which, though not observed with the naked eye or even under X-ray examination, constitute a hidden weakness which will sooner or later develop a defect under shock load. Similarly, such stresses in castings, subject to extreme variations in temperature, may bring about cracks during service.

The proper venting of cores is another essential point which requires most careful consideration, also their assembly in the mould, in order that the core vents may be linked through the mould to the outside of the moulding box, otherwise serious defects are bound to appear in the casting.

The Wood and Water Method

The foregoing remarks have briefly indicated the types of mould and core considered the best to allow of contraction being obtained on steel, iron and brass castings, without any serious defect developing in the casting, but there are

numerous methods in use in this and every other country. It has been suggested only recently, that blocks of wood be carefully embedded at various points in the mould or core, and after their removal water should be poured into the aperture just after the mould has been cast.

The method has been tried with the supposition that the water would soon boil, thereby destroying the bond in the sand, which breaks up in the mould quickly, and allows the casting to contract at that part. Apart from the danger associated with such a method, it is extremely difficult to appreciate how such could become a practical proposition, and, in addition, it is difficult to understand how it could be useful, as the cooling would be localised, and would tend to accelerate contraction at local parts where it might be used, and thus throw the casting out of shape or crack it elsewhere.

Fig. 98 illustrates a method which has been found very effective, and is more practicable. The thickness of the wall of sand encircling this core must be determined by the weight and thickness of the casting. The wall referred to is shown at "A," and the part marked "B" can be packed with dry cinder material, whilst that marked "C" shows three grooves made in the core by means of wood strips, which are placed in the corebox before core manufacture commences.

Here again the distance from the corebox at which these strips are placed can only be determined by the weight and thickness of the casting being dealt with, but, assuming that a core is being made 12 in. dia., the strips for the grooves could commence at 2 in. and taper down to $\frac{1}{2}$ in., the $\frac{1}{2}$-in. end being placed $\frac{3}{4}$ in. from the face of the core. When these strips are drawn away from the corebox, they can be filled with a sea sand, or any other fine silica sand which will run when dry. This sand can be backed with a pad of floor sand, shown at "D," and the cinder material afterwards packed in.

On the other hand, governed by the class of casting being dealt with, the mould could be

Fig. 66. The Removal of Drawbacks.

Fig. 67. Removal of First Piece of Pattern.

FIG. 68. THE OTHER MAIN PIECE OF PATTERN BEING REMOVED

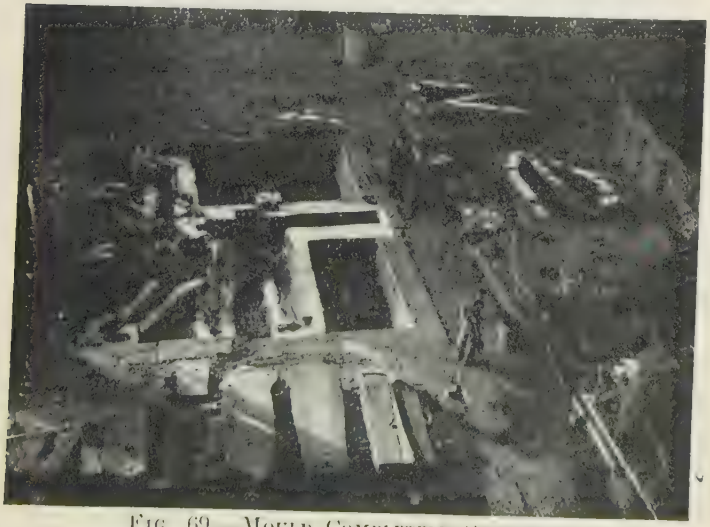


FIG. 69. MOULD COMPLETELY STRIPPED.

cast with such a core in skeleton form without any packing at "B," "C" and "D." If a core iron is used on such cores, it could be carried through the gaps as shown at "E," or if made in oil sand, in many cases no core iron would be required. Cores of many kinds could be split with these gaps, as shown at "F," and afterwards built up, but it has been found they can be made in one piece without any difficulty by a good craftsman.

It will appear difficult to understand by the non-technical person why all this procedure is necessary, but to the technical person with experience it is obvious that the small web of sand between "C" and "G" will soon get hot after the mould has been poured, and thereby become weak at that part, and thus allow the core to collapse under the slight pressure load of contraction.

A Tunnel Analogy

In addition to this, during the easing operation or removal of the cores from the casting whilst it is hot, the core irons can be struck in these grooves with a bar, thereby causing the core to break up easier, and saving much time, which is important at this period of the work. A round core which has been dried is similar to a tunnel so far as strength is concerned, and the coremaker should endeavour to see that the key brick is easily removable in any core he makes, so as to enable same to collapse, as would be the case with a tunnel or arch when the key brick is removed.

Choice of Sands

Another very extensive and important phase connected with the foundry is that of the correct classes of moulding and core sands, and it goes without saying that this is one of the most important subjects, if good results are to be obtained. Much has been published recently concerning the scientific control of foundry moulding and core sands, also on the question of synthetic sands. In the latter case, one might suggest that these classes of sand have been used

over a great number of years, and there is nothing new in their use, so far as the practical side is concerned.

In the selection of a sand to make a mould or core, one has to consider how it will stand up to the method of running, *i.e.*, is the job being cast from the top or bottom of the mould, or is it to be cast on a declivity? The position in which a job is run is a very important factor in obtaining a good casting (this has been referred to previously). The selection of sand, therefore, needs to be made to meet these conditions, as moulds cast from the top or on a declivity will break up on the face if the sand is not correctly selected for such methods.

A perfect-looking steel casting, on the skin, can be obtained with very cheap sand, under some methods of running. One has to look a little further than this, however, if quality castings are required, and, in doing so, one will perhaps have to pay a little more for the sand, as it is the finished-casting result which is of major importance.

Temperature of Moulds

The higher the temperature a dry-sand mould for a steel casting is cast the better it is, as the sand in the mould and core becomes soft sooner when the heat is transmitted from the metal. This condition then surely assists the contraction and helps considerably to keep away hot tears from steel castings. A great deal of excellent work in connection with moulding sand for cast iron has been done in recent years by the B.C.I.R.A., and this work should have assisted very much foundries manufacturing standard products which are of a repetition nature, on which the sand can be kept at a constant quality. In foundries not dealing with repetition work, however, much different treatment is necessary.

Repetition work is invariably moulded in green sand, and the sand under these conditions is easier controlled scientifically than in a foundry which is working on green sand, dry sand and loam work. In addition, the repetition

Fig. 70.—Showing Method of Drying.

Fig. 71.—Closing Operations Commenced.

FIG. 72.—ASSEMBLED DRAWBACKS.

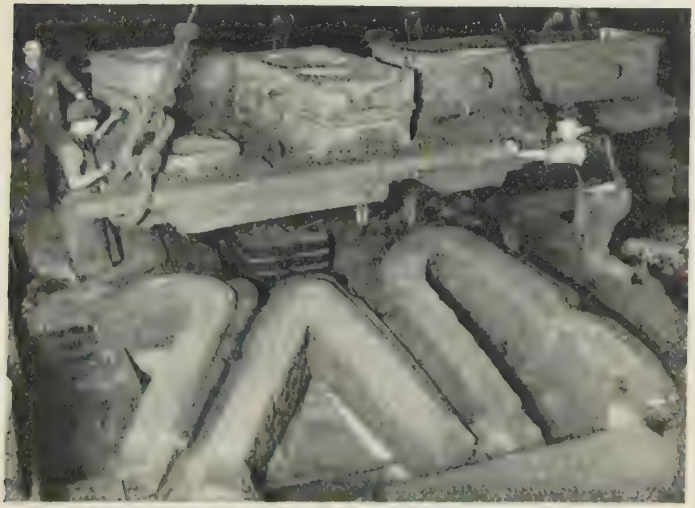


FIG. 73.—LARGE TOP PART BEING ASSEMBLED.

product manufactured on a green-sand basis is generally a design of casting kept constant as regards thickness, and any changes that do take place are usually of very minor nature and cause little variation in method of manufacture.

Grain Splitting

During recent months much has been written concerning bonding clays, regarding which the addition of pounds or ounces will make floor sand last for ever, with small additions of silica sand. These procedures need very careful thought before being put into use, otherwise the foundry commitments may soon lag behind in deliveries, due to trouble that may be experienced after a short period of working. The continuous cracking of the grain is the result caused by the molten metal coming continually in contact, and this condition makes the floor sand fine.

An instance of this is illustrated by a silica sand which was recently tested in its normal condition by being heated up once to 1,400 deg. C., which is about the usual modern casting temperature for cast iron. This silica sand as received from an English supply was of very good quality, and 0.4 per cent. passed through a 200-mesh sieve in its normal condition after being dried. After heating at 1,400 deg. C., 2.1 per cent. passed through the same sieve, thus showing a splitting up of the grain to the extent mentioned with the one heating.

It is therefore reasonable to assume that by continual heatings of this description taking place day after day in the foundry when moulds are cast, the grain size would continue to break down in such manner that it would become as fine as gunpowder and permeability would entirely disappear.

New sand, therefore, should be used in a sufficient proportion to meet this condition, if these clays, which are recommended so much, be used. One of the clays in use, on being passed over a 200-mesh sieve, 83.7 per cent. passed through, which gives an indication of its fine silky nature. If large quantities be used, one can appreciate what condition such material will finally leave

floor sand in after a few weeks' use, so it is necessary that careful consideration be given before commencing.

One wonders why fireclays should be used for the purpose described when such excellent natural sands are obtainable locally in practically every district throughout the country, especially for use in iron and non-ferrous production. The B.C.I.R.A. have published a list of these local sands, which can be obtained at very small cost in all the districts throughout the country, and, carefully handled, such sands give the results generally required without resorting to such fine powdery materials. When everything is calculated, what saving in cost is obtained as against the use of natural sands? In this respect much depends on the district.

It cannot be stated that the local sands referred to can be generally used on a standard mix with success on any thickness of casting, but the foundryman, by adding a little more new sand to his floor sand, to meet heavy-section thicknesses, can generally get better results than can be obtained from the use of other materials.

In the production of steel, however, long experience has taught one that synthetic sands are the best to use. The high temperatures at which steel is cast make it essential that highly-refractory materials only be used in the manufacture of moulds and cores. In addition, the synthetic sands made from them must be sufficiently bonded to withstand the wash of the metal, especially so when runners are placed at the top of the moulds, which, as has been stated, is the best position in which to place them to obtain sound castings.

There are many classes of moulding sands in use for steel-casting production in this country and abroad, but a better class of natural sand seems to be available for steel on the Continent than in England. In foundries where repetition work only is made, one class of sand can be conveniently used, and good results obtained, but, unfortunately, this cannot be done satisfactorily in foundries dealing with different types and classes of work.

Fig. 74.—The Last Small Top Part about to be Put in Position.

Fig. 75.—The Final Top Part in Position, completing the Assembly of Mould.

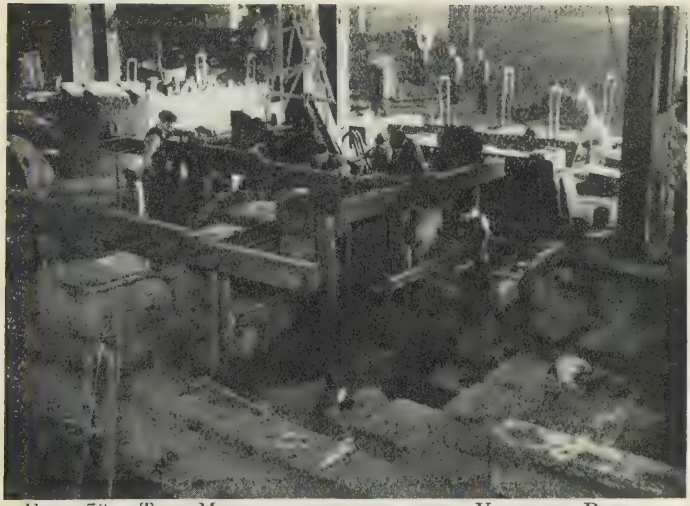


FIG. 76.—THE MOULD COMPLETED—THE VARIOUS PARTS BOUND TOGETHER TO THE BOTTOM PLATE BY MEANS OF CLAMPS AND CROSS-BINDERS.

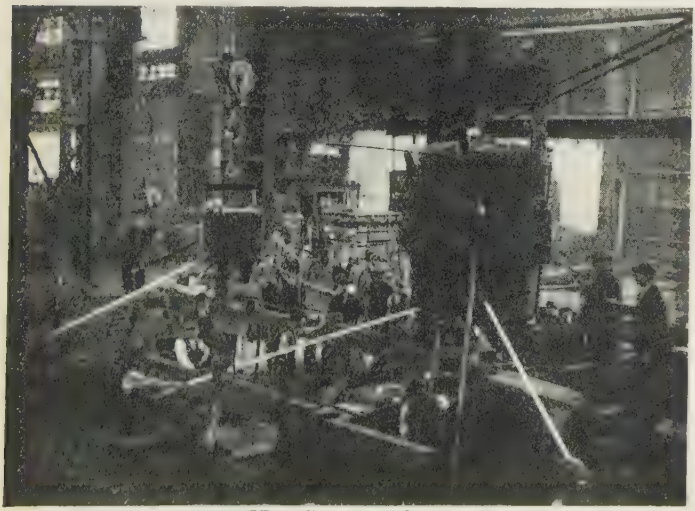


FIG. 77.—CASTING OPERATION.

The main reason is, that castings of heavy and light type cannot be successfully made unless the facing sand is graded to withstand the high temperature at heavy parts, and to be weak enough at the light parts not to retard contraction. To sum up, the only practicable method known is to make a variety of sands to meet the variety of castings and the varying thicknesses relating thereto.

It will be seen from Fig. 99 that the heavy body of metal round the boss has caused the sand to break up and the metal to eat its way into the face. The same remarks apply in the case of the extra metal thickness on the arm, where it will be seen the sand has failed to stand up. It will also be observed that the sand on the thinner sections has stood up much better, the casting being cleaner at those parts (Fig. 99). The break up of this sand was caused through its bond being insufficient to bind the grains of the refractory materials together. The trouble was not due to soft ramming or packing of the sand round the pattern, as may be surmised, the mould being carefully examined as to this after the pattern was drawn.

It has been mentioned that synthetic sands are the best to use for the making of moulds where a variety of steel castings are produced, the reason being that grades of sand can then be made of varying bond strengths.

The bond is obtained by adding a siliceous clay to the refractory materials in use, these materials being as follow:—Belgian silica sand; English silica sand; ganister stone, ground after being burnt to 850 deg. C., which can be done at little cost during the annealing of castings; old firebricks, and reclaimed sand from castings. The purer in silica the moulding sands are, *i.e.*, the less amount of fusible material contained therein, the more refractory is the sand, and the better will it withstand temperature.

It is not always desirable to have the sands too pure, as in this condition they break up too readily, and cause what is shown in Fig. 99.

Therefore the mixtures sought are those sufficiently strong in bond so that they will hold together during the casting of the mould and the cooling to solidification stage. In addition, they must be sufficiently weak in other places not to retard contraction from solidification until the casting is cold.

Of the materials mentioned, Belgian silica sands are probably the best from a refractory point of view, as they can be obtained much purer than English grades; also, they are of more regular grain size. English silica sands are used in many foundries, but do not resist temperatures in steel-casting production so effectively as those from the Continent. When using those sands, it is necessary to add some bonding material in order to make them sufficiently plastic to hold together, otherwise a mould or core could not be made from them.

The grades of silica rock, or ganister stone obtainable in this country, are also varied in quality, but excellent materials are available which contain up to 97 per cent. silica. These, when treated, are very good for use in synthetic steel moulding sands, but here again, bonding materials are required to give the strength for moulding purposes. The best quality known to the authors is obtained from the Welsh coast, a large deposit being in existence there on which a great deal of scientific research work could be done to advantage.

Old firebricks, which have been in fairly high temperatures, are also a good material after all slag is removed. The best refractory, however, is found to be the old clay crucible pot, which has been used for the melting of steel. This material is the best known in connection with synthetic-sand mixtures for steel production, especially on cores for pressure castings.

The method to use is to clean away any slag and then grind the material until it will pass through a $\frac{3}{32}$-in. sieve. It is then used with other siliceous materials which have been mentioned, together with old facing sand gathered

FIG. 78.—EASING THE CASTING.

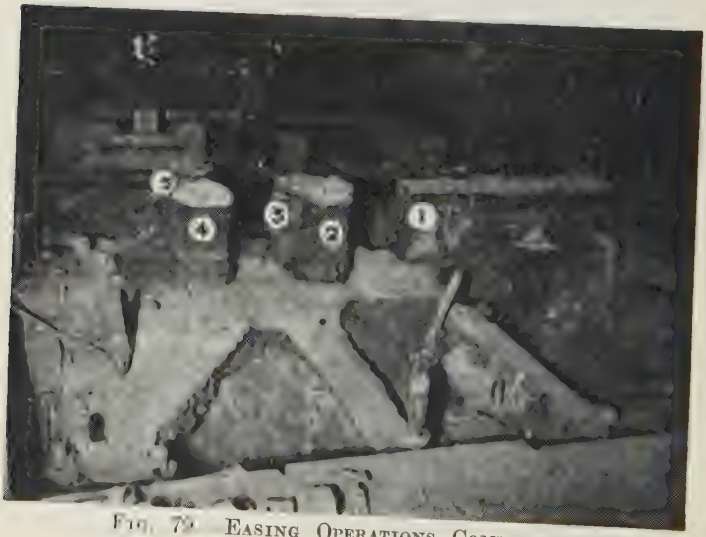


FIG. 79.—EASING OPERATIONS COMPLETED.

FIG. 80.—THE CASTING IN THE ANNEALING FURNACE.

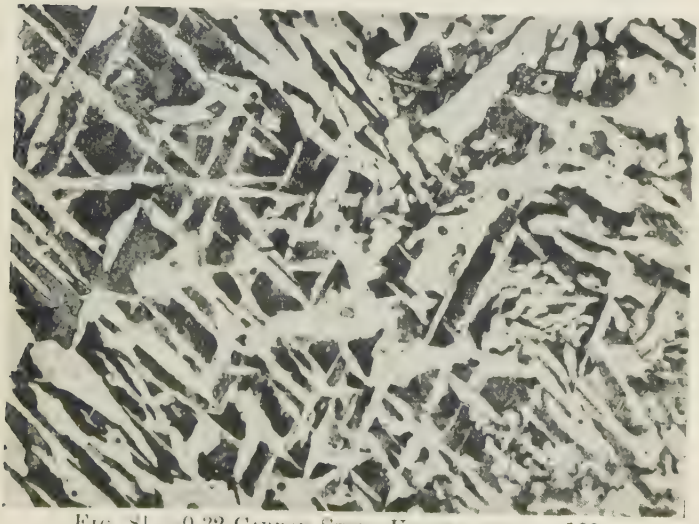


FIG. 81.—0.32 CARBON STEEL UNANNEALED × 100.

from the castings. If these materials are used and prepared carefully, the sands produced therefrom give less trouble than many of the facing sands at present on the market in this country, *i.e.*, for the varied classes of moulds, and especially for cores used in pressure work.

Mould Facings

The question of paints for facing cores and moulds should be very carefully considered, as they should only contain small amounts of any materials which fuse below the casting temperature of the metal. In addition, it is necessary to have them fine enough to penetrate between the grains of sand all over the face of the mould. Also, the bonding material used should be highly refractory. A very satisfactory and reliable silica paint is produced in Wales, but good paints can be made by the user. The quality is then controllable, as it is easy to keep constant on account of being mixed in one's own mills—a small ball mill only being necessary for this purpose.

Tar-bonded sands have been spoken of recently as being useful on account of their easy collapse when the metal comes in contact. These sands have been used extensively in the past, and provided they are used in a proper manner, excellent results are obtainable, but only a very small quantity of tar is necessary. The authors are not, however, generally in favour of the use of tar facings, on account of the potential carbon pick-up by the metal, which it has been definitely proved takes place. In addition, all moulds on which tar is used in the facings should be subjected to high-temperature drying, so that there is no possibility of gas being generated, as such gas is the cause of serious defects.

Lines for Research

It has been noted that research work is proceeding on moulding sands, and, in the opinion of many, the best lines on which to proceed would be to give greater attention to sands for use in steel foundries, as when research work has

been successful on these, iron and non-ferrous problems in this connection will be more easily solved, as the casting temperatures are so much lower. The technical side should work closely in touch with the scientific side to obtain the desired result.

The subject is a very large one, and, as pointed out, sands are required to serve so many purposes in the manufacture of reliable steel castings, especially for pressure service. Research needs to adhere closely to contraction troubles, otherwise progress will not be made. The foundryman should give his views and table his troubles so that he may be assisted fully by such research work.

Sands require the most urgent investigation, and any committee formed to deal with the subject should be a combined one of those who have had long practical experience on the one side and on the other, scientists who are not afraid to come into the foundry and investigate fully the practical man's troubles. In addition, the best known refractory materials should be all gathered together and tried out under varying conditions.

Labour Selection

The selection of craftsmen, that is the moulder and the coremaker, is also a very important question where the quality of the finished casting is concerned, and, in a foundry where varying classes of castings are manufactured, *i.e.*, structural work, land and marine turbines, Diesel engine work, and castings which are required for gun-mountings, it is most important that the foreman in the foundry should know each of his men who are competent to handle the complicated castings on the lines indicated. Moulds and cores should not only be made to look well finished on the moulding floor, but they should be built on sufficiently weak lines, otherwise the desired result is not obtained.

Foundries that have been producing an article on repetition basis, are usually worked with what are called semi- and un-skilled labour, and, generally, this type of labour is useless in foundries

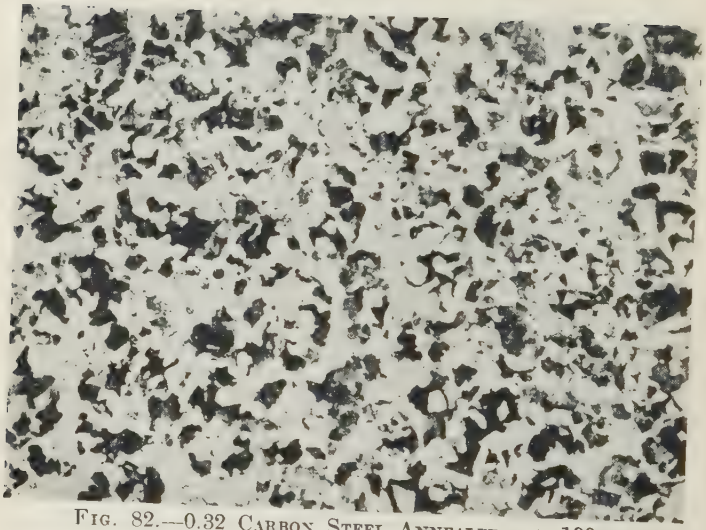


FIG. 82.—0.32 CARBON STEEL ANNEALED. × 100.

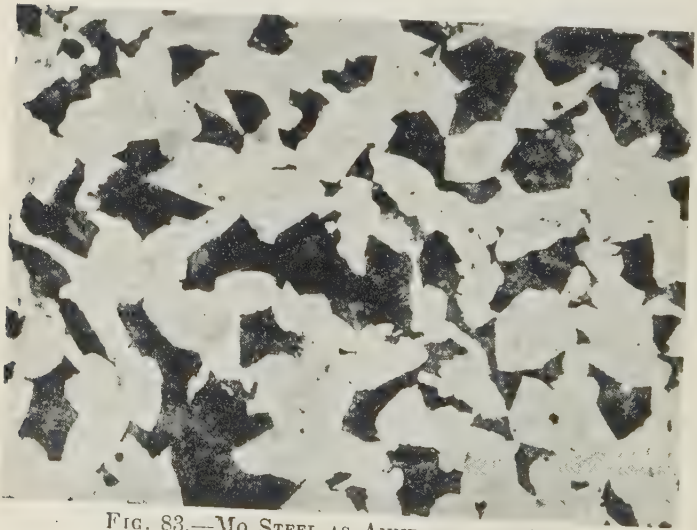


FIG. 83.—Mo STEEL AS ANNEALED. × 100.

producing the class of castings dealt with, and the same remarks apply to what are called the skilled class of moulder and coremaker who have been used to producing plain types of castings, as moulds for such castings do not require the treatment necessary for pressure and other complicated work.

It is, therefore, essential that the supervisor in the foundry pick out the highest-skilled craftsmen to handle the more important moulds and

Fig. 84.—Mo Steel Quenched in Oil from 900 deg. C. Tempered from 600 deg. C. × 100.

cores to make sure they be made on the lines indicated as there is a great difference in the grades of ability of moulders and coremakers.

Defective Castings

Defects in castings are caused through many faults, which can be attributed to design, patternmaking, supervision, moulding, coremaking, metallurgy and other and more minor operations connected with manufacture, also inferior or

unsuitable materials as mentioned. It is a very extensive subject, but it may be an advantage to go briefly into the matter, so that the overseer who examines the casting and may not have had foundry experience, will be able to lighten the load of those connected with manufacture when he examines any defect shown to him during his daily tours round the defects department.

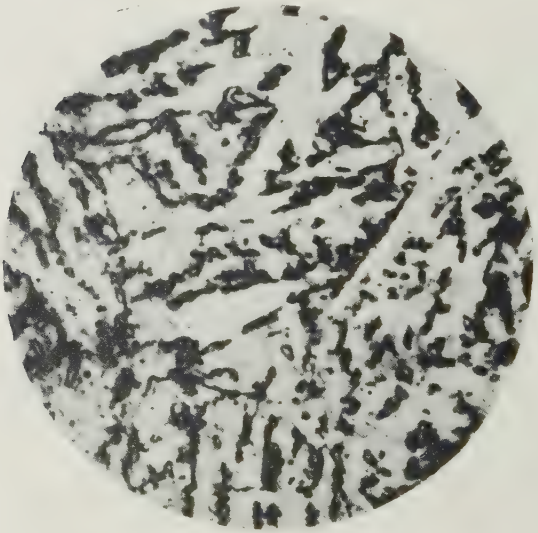


Fig. 85. — Mo Steel Quenched in Oil from 900 deg. C., Tempered from 600 deg. C. × 1,500.

The defect which is these days usually considered the most serious is that which the overseer calls a crack, but which is better known in the foundry as a hot tear, and is seen more on a steel casting than on iron or non-ferrous. The cause of these hot tears has already been touched upon briefly, and those castings upon which they can be seen with the naked eye are generally rejected before they leave the foundry. In other

cases they are found during machining, or when the casting is subjected to water pressure, or X-Ray examination.

The causes of these hot tears can be definitely identified with the contraction of the casting being retarded, having been held by some part

FIG. 86. — THE SURPLUS METAL BEING MACHINED FROM THOSE PLACES FROM WHICH THE FEEDERS HAVE BEEN REMOVED.

of the mould or core during the cooling period. It will be noticed that a contraction tear is shown running transversely, between the flange and one of the seatings. This tear is not due to the core binding the contraction through the diameter of the pipe, but is definitely caused by

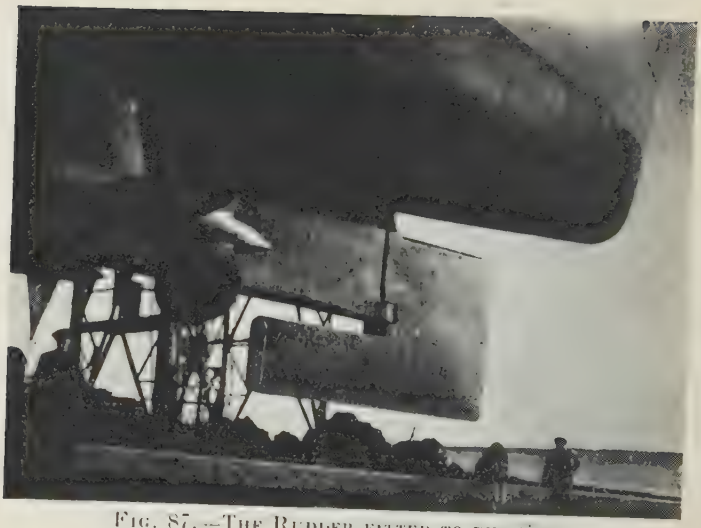


FIG. 87.—THE RUDDER FITTED TO THE SHIP.

FIG. 88.—MODERN DESIGN OF STERN FRAME.

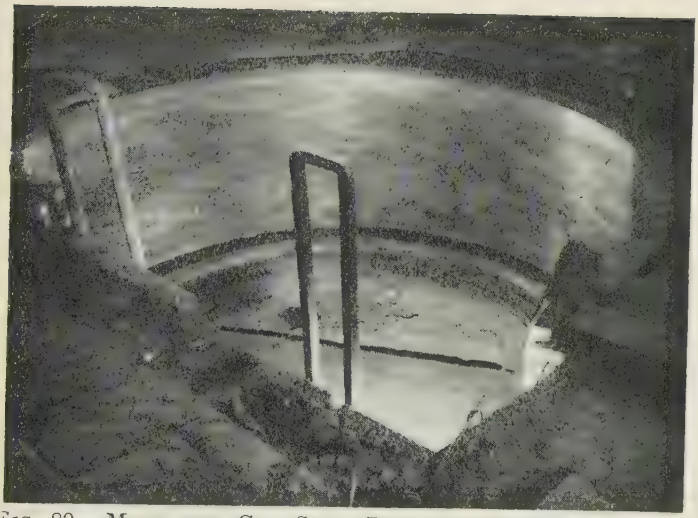


FIG. 89.—MOULD FOR CAST-STEEL DRUM FOR LARGE WINDER.

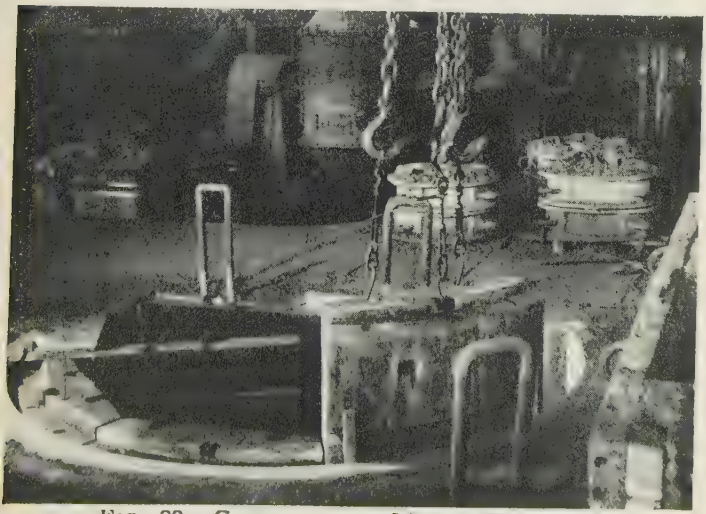


FIG. 90.—CORING-UP THE MOULD (FIG. 89).

the casting being held by the seating and the flange, which has retarded the contraction of the casting lengthways.

If the tear had been traversing the length between the flanges, the foundryman would have immediately attributed the cause to the core having been made too rigid. It is therefore necessary in this case, to see that the replace casting is manufactured with a lighter mould, so that no part of the casting be held when it commences to contract.

The place where this casting cracked was under a feeder. The extra heat from this feeder weakened the casting to some extent at the defective part, and when contraction commenced, the casting naturally cracked at that part.

A material at this temperature is obviously extremely weak, and no resistance must be offered by the sand to free contraction, or the stresses set up will prove too much for the material to resist. Fig. 101 shows a close-up of this hot tear. To eliminate such a defect a weaker mould is necessary, and the method adopted of constructing the mould with cavities in front of those parts held by the sand, would give the desired result if carefully carried out.

The cavities referred to are shown inside each of the flanges in Fig. 102. They are formed by cutting away the sand during the ramming of the mould, and filling them with cinder material, or fine sand. It is also necessary to carry the holes through the top half of the mould to meet the cavities.

This method enables the moulder to insert a bar in the holes in the top part, and knock it through the entire mould, which allows the cinder or fine sand to run away through the bottom of the mould. The flanges are then free to move, and the contraction is not hindered by projections being anchored in solid sand. The contraction on this width in cast steel is approximately four and a-half inches, *i.e.*, when cold the casting is four and a-half inches smaller than the pattern.

The hooks shown on the ends of the arms of the casting, shown in Fig. 103, were dealt with during moulding on the same lines as that

shown in Fig. 102. It is essential that cavities be made inside these hooks so that the mould be easily removed during the easing stages shortly after casting. If this were not done the arms would be anchored, and serious contraction defects, *i.e.*, hot tears, would occur close to the heavy section nearest to the hook shape on the end of the arms.

Green Sand Moulds

Various methods are used to weaken moulds at the parts similar to those illustrated, the best known is to cast in moulds that are not dried, *i.e.*, what is termed in the trade "green sand moulds." The latter method is not reliable, however, except on very small work, on account of undried moulds being too weak to resist the wash of metal. The foundryman therefore has of necessity to resort to such methods as described when the moulds are dried.

The bars which carry the weight of sand in Fig. 104, inside the moulding box frame are all loose, and are tapered, so as to allow quick and easy removal after casting has taken place. Some of the holes seen are for feeding purposes, and the remainder are connected to grooves in the mould for quick removal of sand, which is in front of projections of metal on the casting, and therefore require to move inwards during contraction as shown in Fig. 102.

The two bottom halves of moulds shown in Figs. 105 and 106 indicate how the moulding boxes are screwed together in pieces, to allow them to be easily dismantled after the moulds are poured. These two moulds are seen with cores assembled, and are for the top and bottom halves of a high-pressure cast-steel turbine for marine service.

The top runners on each side and at each end of the moulds are so placed to obtain even temperature throughout the length, and also to obtain hot metal in the feeders, which can be seen in Fig. 104. These illustrations are shown to indicate the methods used when the mould is being constructed, so as to eliminate hot tears.

Fig. 91.—Dressing the Casting (Fig. 89).

Fig. 92.—Irons Bent into Shape ready for Building up the Core.

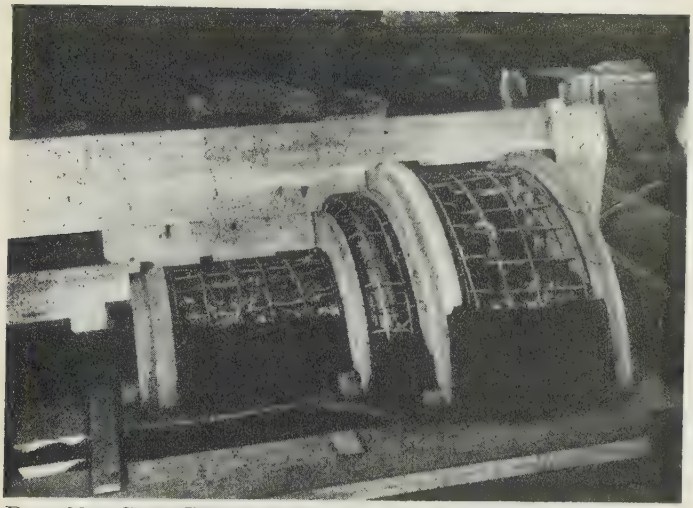


FIG. 93.—CORE PARTLY PACKED IN THE CENTRE WITH CINDER MATERIAL.

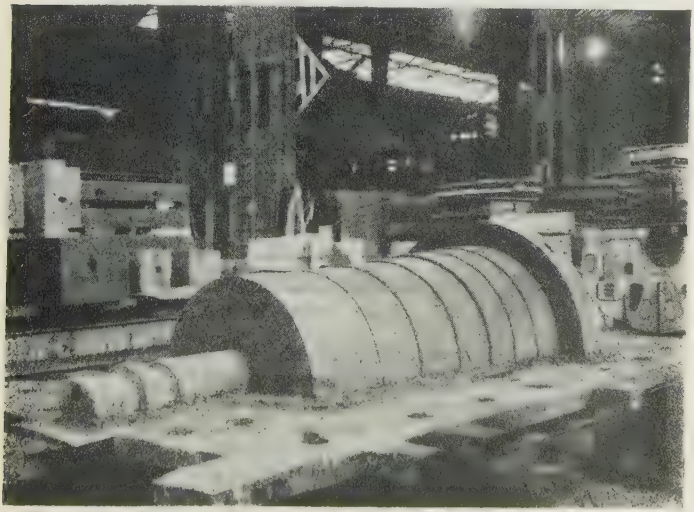


FIG. 94.—LARGE CORE FOR A CAST-STEEL HALF-TURBINE SECTION.

Another defect generally referred to by many overseers as a blowhole, is the drawn cavity, or, to give it the correct term, shrinkage cavity. These cavities occur usually in a part of the casting where the section alters. The defect occurs when the volume of liquid metal changes

Fig. 95.—Cast-Steel Wheel.

from the temperature at which it is cast to that at which it is just commencing to solidify.

The foundryman should make good this shrinkage by the use of feeders, which must be judiciously placed in correct positions and be of the correct design. The "T"-section piece, Fig. 107, was cut from a steel casting after being radiographed. On being sectioned through A—B,

the shrinkage cavity shown at G was found. The design, it will be seen, shows the web of metal at C, $1\frac{1}{2}$ in. thick, and at D, $\frac{3}{4}$ in. thick; this condition brings about two periods of solidification, *i.e.*, section D cools before C, and the shrinkage defect at G, naturally occurred, owing to no feeder having been used.

To eliminate this defect, the moulder would thicken up section D on the upper side as cast, as shown in the shaded portion at E; the altera-

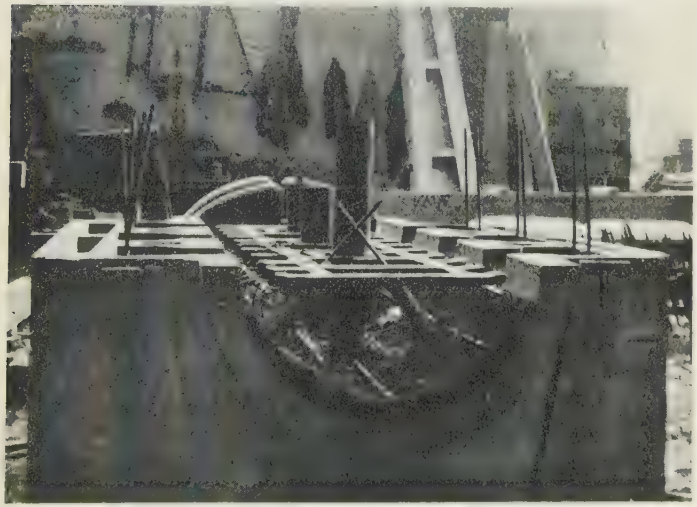


Fig. 96.—Manufacture of Core for a 25-ton Casting.

tion would then allow him to add a feeder at F, which would be effective.

The two pieces of metal in Fig. 108 are bosses, one cut from a vertical wall as cast, and the other from a plate of metal over a core. They were both taken from a casting which had been radiographed. The cavity shown in the vertical piece as cast is again a shrinkage defect caused through the change in section. This could be eliminated by carrying through a piece of extra metal as shown at C, and placing a feeder over

the part. The other piece, which was taken from the plate of metal over the core, was found to be sound, as it was in a horizontal position when cast. In addition, a boss in the position shown can be fed by a feeder as shown at *D*, without having to add extra metal to the casting

FIG. 97.—THE CORE COMPLETED AND BEING LOWERED INTO THE MOULD.

as is necessary in the vertical position shown at C.

The defect at A, Fig. 109, would be prevented by adding metal at B, and placing a feeder at C. The radiograph examination of such defects as described is shown in Figs. 110 and 111. The

section, 1½ in. thick, illustrating shrinkage piping, due to insufficient feeding, is shown in the radiograph. After cutting the section the typical "V" piping is seen here in the actual material, and it will be noted how important it becomes to see that sufficient feeding and good-running arrangements are allowed for, during the early stages of manufacture.

Fig. 112 is that of a casting with a shrinkage defect, and is known in the foundry as drawn metal. The term means that a heavy section

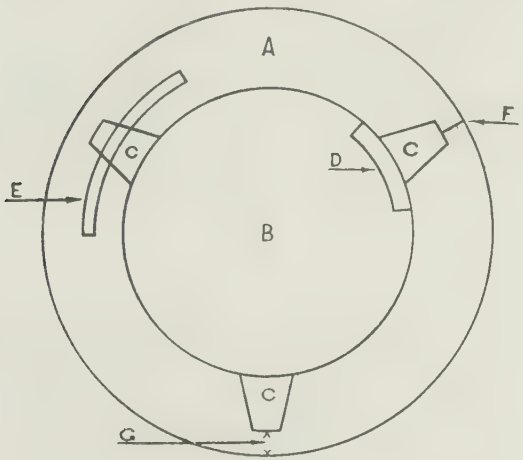


Fig. 98.—A Section of a Round Core.

somewhere close to the defect has drawn away the metal. It indicates how important it is for the foundryman to examine each defect and correctly diagnose before attempting to remedy it. This defect is really due to shrinkage, and is not in any way associated with the blowhole defect.

Shrinkage cavities are produced during the cooling of the metal through the plastic range, and result from a deficiency of molten metal to feed the point concerned. Such cavities are not smooth as in the case of blowholes, but usually

Fig. 99.—A Casting made in a Sand which had been Prepared to Mould a Lighter Class of Casting.

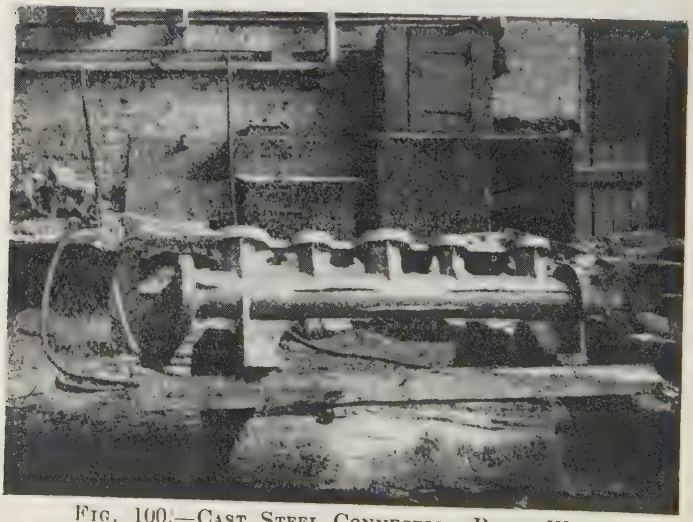


Fig. 100.—Cast Steel Connection Piece With Five Branches and Two Seatings.

show a dendritic surface (Fig. 113). This formation is a result of the natural tendency of all metals to produce branches of crystal growth. It, however, is impossible under perfect conditions owing to adjacent crystals impeding one another.

Fig. 114 is that of a specimen of steel showing dendritic formation, the piece being broken from the inside of a feeder. As a matter of interest,

Fig. 101.—Close-up of the Defect known as "Hot Tear."

the sample is a particularly good illustration of a dendrite.

The specification for the casting shown in Fig. 115 was that a 9-in. hole or core had to be drilled or cast down the rod for lightening purposes. The only safe method in the foundry to get a sound casting, was to cast the rod solid, so that feed could be supplied to adjoining thick sections. This method was carried out and a feeder was added 13 ft. 6 in. long, resulting in a perfect casting. A cheaper casting could have

been produced by using a core, but shrinkage defects would have been almost certain to develop in the heavy junctions.

The feeders on the two defective faces shown in Fig. 116 were placed on the side of the casting in this instance on account of bosses, where the defects are seen, being placed at an angle in the design. In instances of this kind, it is considered the best practice to add sufficient height of feeder above the top of the casting (as cast), so as to obtain gravity pressure to hold up sections adjoining the bosses until they solidify. A shrinkage cavity, shown in Fig. 117, under

FIG. 102.—SECTION OF MOULD FOR PRESSURE CASTING.

one of the feeders which has been removed. This casting has another feeder close to the one showing the defect, which it will be noted is less in size. It has been found that two feeders close together of different sizes, similar to the two shown, cause a defect of this kind, especially when the casting thickness between the feeders is approximately the same thickness as the parts being fed. This is due to the metal in the larger feeder on the high part of the casting supplying feed to the feeder on the lower face of the casting. This defect would be eliminated by removing the smaller feeder, leaving the larger one to feed the casting.

In the feeding of castings, the supervisor in the foundry must give every job very careful thought before deciding the procedure, as badly positioned feeders, and those of unsatisfactory design, cause a high percentage of defective castings. Many serious defects come from this section of the moulder's work, and the placing of runners to get hot metal in the feeders is important, so that it can supply a flow of metal to the parts which solidify last.

In Fig. 118 can be seen the shrinkage cavity, such as was shown in Fig. 117. It is shown at D, under feeder A. Feeder B was eliminated on account of feeder A being sufficient, in view of the section at C being equal in thickness to

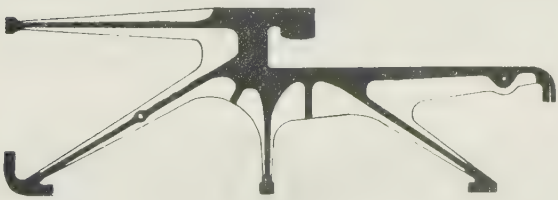


FIG. 103.—PART SECTION OF A CASTING 24 FT. WIDE.

the part under B. It is better practice in instances of this kind to use one feeder on the high flange, but it is necessary to take careful note of section C, as the thickness here controls the decision, as, if this thickness were less, two feeders would be necessary. Such is the decision that has to be made by the supervisor before commencing to manufacture.

Having described some of the causes of shrinkage defects in steel castings, a few pictures of castings with feeders attached, might be of interest. The flanges of the casting, shown in Fig. 119, were 10 in. thick, and the body thickness 3 in. Ten feeders were used, the height of which was greater than the depth of the casting.

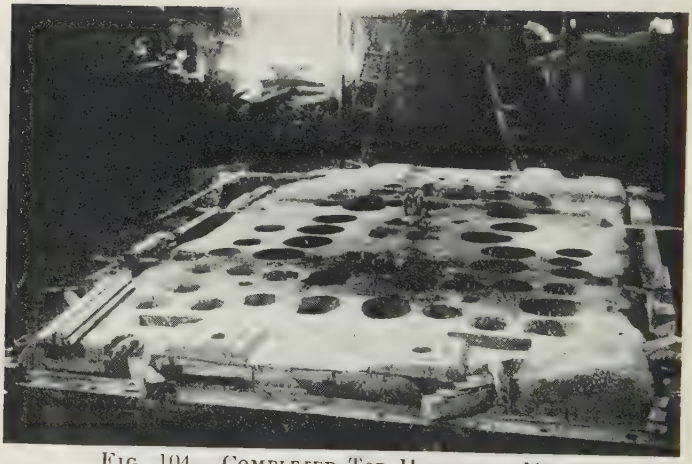


Fig. 104.—Completed Top Half of a Mould for a Large Steel Turbine Casting.

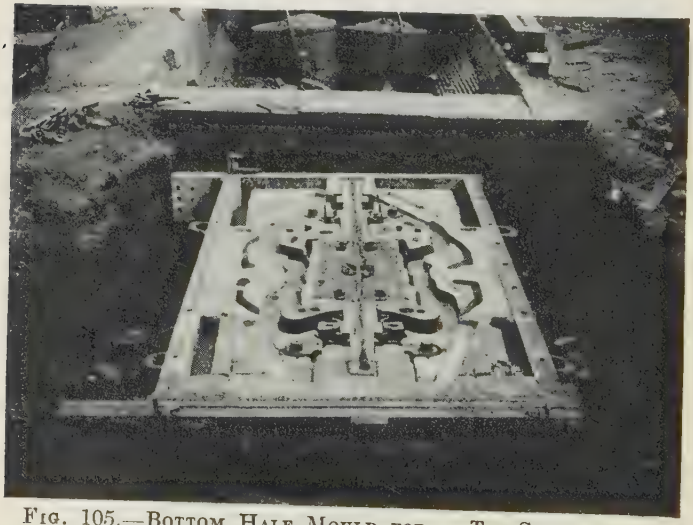


Fig. 105.—Bottom Half Mould for a Top Section of a H.P. Cast-Steel Turbine.

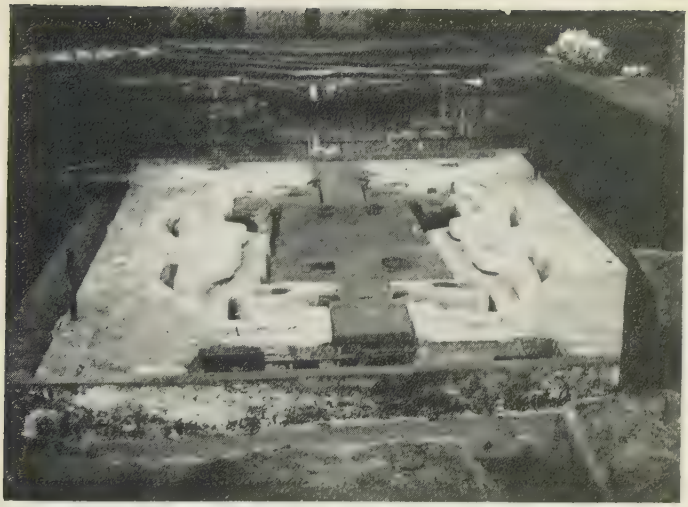


FIG. 106.—BOTTOM HALF MOULD FOR THE LOWER SECTION OF A H.P. CAST-STEEL TURBINE.

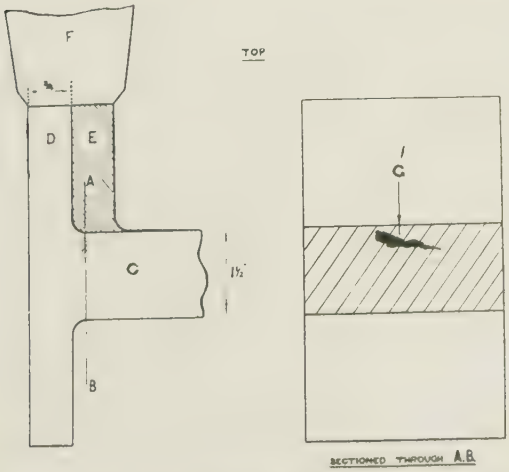


FIG. 107.—"T" SECTION SHOWING SHRINKAGE DEFECT.

The weight of the metal used in feeders shown in Figs. 119 and 120 was approximately 12 tons, the casting as delivered being only 7 tons.

The casting illustrated in Fig. 121 had ten feeders attached, one of which can be seen cut through, but not removed from the casting. The position of the remaining nine were between each of the inlets of the valve, in order to feed without any obstruction by the core, which cuts through on the face of each side of the valve. This particular casting took over 20 tons of metal to cast, and the valve when delivered weighed only 8 tons.

To obtain quality in steel castings of this description, the only method which has proved effective in eliminating shrinkage defects is that of using feeders of sufficient size to deal with the heavy sections of metal in the design. The cost of removing such feeders is obviously high, and buyers of steel castings who require the best article should bear this in mind, as sound castings of this description cannot be produced unless a large quantity of metal be used above the finished weight of the casting. Cast-steel land-turbine pieces, shown in Fig. 122, were dealt with on these lines, and satisfactory results were obtained only by observance of the methods indicated.

Blowholes

Another type of defect is that called the blowhole, due to gases which are generated from the facing sand or facings, moisture in the mould, choked vents from cores, or from incorrectly-melted metal. The defect, shown in Fig. 123, was caused through a core under the feeder not having had the vent released, or, in other words, the vent had been choked, the moulder not having given the attention he should have done in its release through the mould.

It will be seen that two of the other positions in the casting from which the feeders have been removed are clear of blowholes, which would not have been the case had the blowholes been

caused through moisture in the mould, the defect in the latter instance usually causing the blowholes to be more generally dispersed over a large area of the casting, a little distance away from the runner.

A typical blowhole defect as shown in Fig. 124, due to moisture or gas generated in the mould from sand or facings. It will be observed that this casting is covered with blowholes on the reverse side to that upon which it was run. The cause of this is the hot metal at this position drying away the moisture or burning away the gas.

The metal during pouring under these conditions is considerably lower in temperature when it reaches the opposite side of the mould, due to having passed through the moisture, which, in a warm dry-sand mould, is in the form of a vapour. The result is that the moisture passes through the metal, which solidifies quickly and causes the defect "blowholes." The metal in the mould under such conditions is very agitated.

This defect in Fig. 125 was caused by gases occurring in the metal and being subsequently released on cooling. The metal has swollen back through the feeder, due to the steel not being thoroughly killed when tapped from the furnace. The blowhole defect is not associated with shrinkage defects or contraction troubles, which cause hot tears. Castings are frequently cut up so that specimens may be obtained for microscopic examination, and while such procedure may be regarded as costly, valuable information has been obtained thereby for the foundryman as a result of the metallographer's work.

Causes of Blowholes

The cause of blowholes has been mentioned, and the two main types are as follow:—(1) Gases occurring in the metal as cast, and subsequently released on cooling, as shown in Fig. 128, and (2) gases from the mould. As regards (1), such gas in the case of steel is liberated from imperfectly killed steel, which

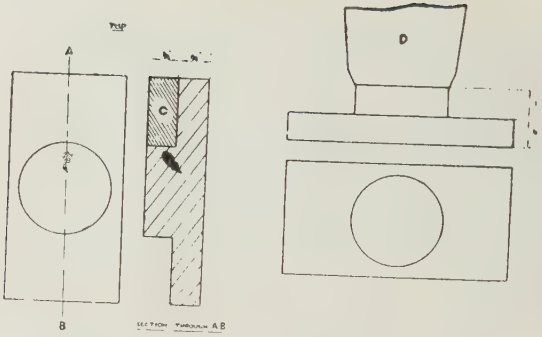


FIG. 108.—TWO PIECES OF METAL CUT FROM A STEEL CASTING.

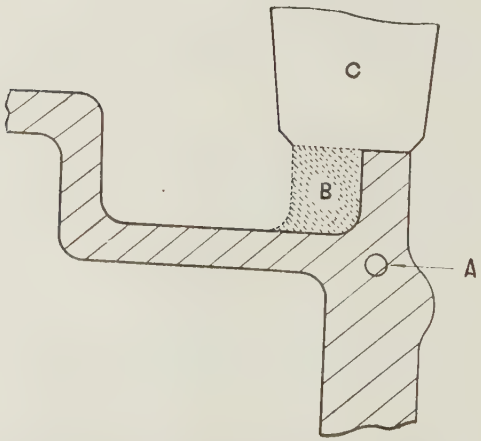


FIG. 109.—A SIMILAR SHRINKAGE DEFECT.

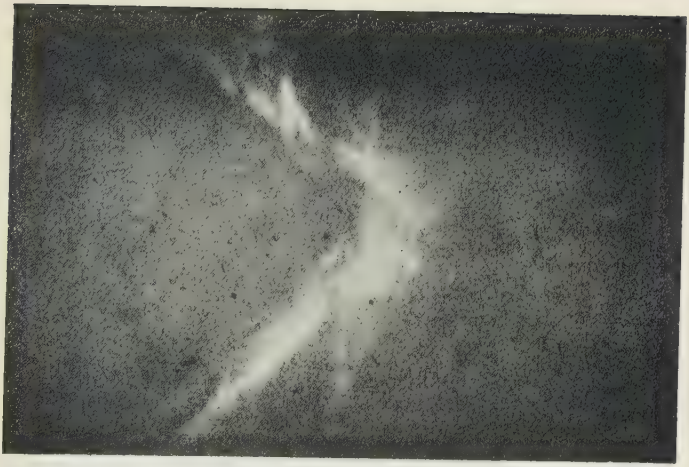


FIG. 110.—RADIOGRAPH SHOWING PIPING.

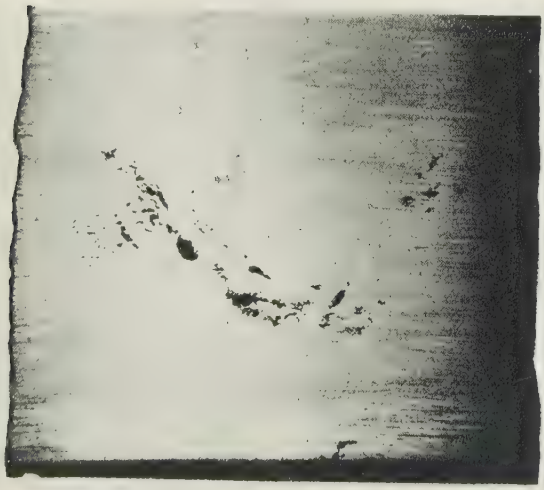


FIG. 111.—SECTION OF "V" PIPING.

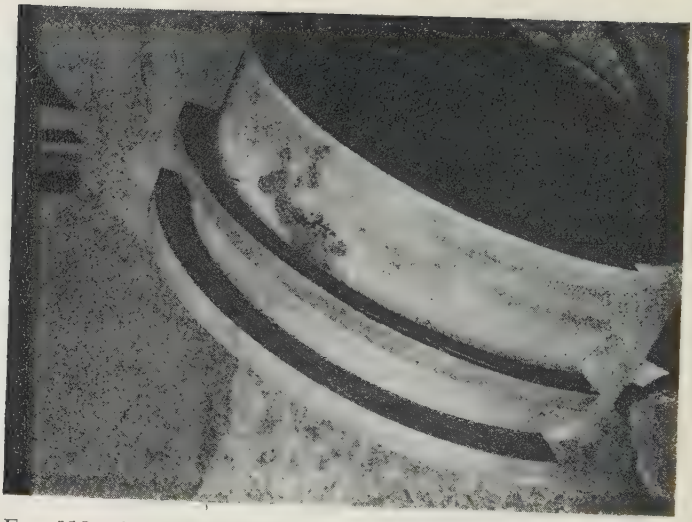


FIG. 112.—TYPICAL SHRINKAGE DEFECT KNOWN IN THE FOUNDRY AS DRAWN METAL DEFECT.

FIG. 113.—SHRINKAGE CAVITY. × 4.

FIG. 114.—SPECIMEN OF STEEL SHOWING DENDRITIC FORMATION.

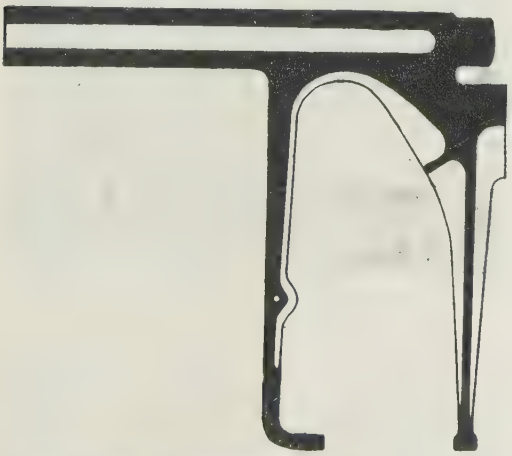


FIG. 115.—A PART SECTION OF LARGE CASTING SHOWING ROD OF METAL CAST ON IT, OVER 13 FT. LONG, 18 IN. DIAMETER.

causes blowholes of bright appearance. Aluminium alloys are particularly susceptible to the solution of gas, which is liberated on cooling, and causes the well-known "pinhole" defect.

Much difficulty is also often experienced from this cause in bronze, a metal which readily take-

FIG. 116.—SHRINKAGE DEFECT IN BOILER STOP VALVE, SHOWN AT A.A.

up furnace gases when heated to high temperatures. Gases are dissolved in quantities proportional to the square root of the pressure, so that natural-draft furnaces are considered superior to forced draft on this account. It is also agreed, that the actual composition of the

furnace atmosphere is of considerable importance in this respect. By rapid cooling, such gases may sometimes be retained in solution in the metal and sound-looking castings obtained, but such methods are poor substitutes for careful control of melting condition, as under such con-

FIG. 117.—SHRINKAGE CAVITY UNDER FEEDER.

ditions the material does not give the required mechanical properties.

As regards (2), it has been mentioned that the troubles may arise from air entrapped in the mould or from the materials from which the mould has been made, or may occur as a result of inadequate venting or insufficient porosity of the sand. These holes usually have an oxidised

appearance. If due to moisture from the mould, the metal surrounding the hole will be decarburised, and microscopic examination will reveal this.

Fig. 126 shows such a hole, surrounded by a decarburised area, and this effect may occur to a considerable depth. Where the hole is due to entrapment of air, the metal is decarburised to a very slight depth only (Fig. 127). These blowholes are usually found round the edges of the casting, at the most remote position from the runner or inlet, where the metal is in a sluggish condition.

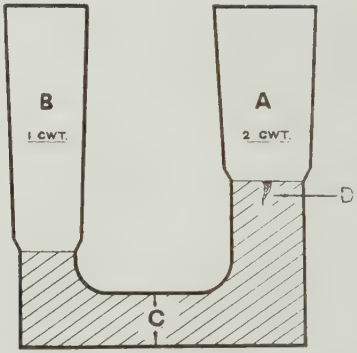


Fig. 118.—Section of Casting (Fig. 117) through Defective Part.

Scabs

The defect shown in Fig. 128 can arise from various causes, the main one being careless moulding. The position of casting in this instance was the bearing face uppermost, so that feeders could be used over the joint face. By this method the core is hung in the top half of the mould, and that any sand in the mould would rise with the metal and get trapped under the core. It is usual in cases of this kind to allow extra metal for machining to clean this away and thus leave the casting clean.

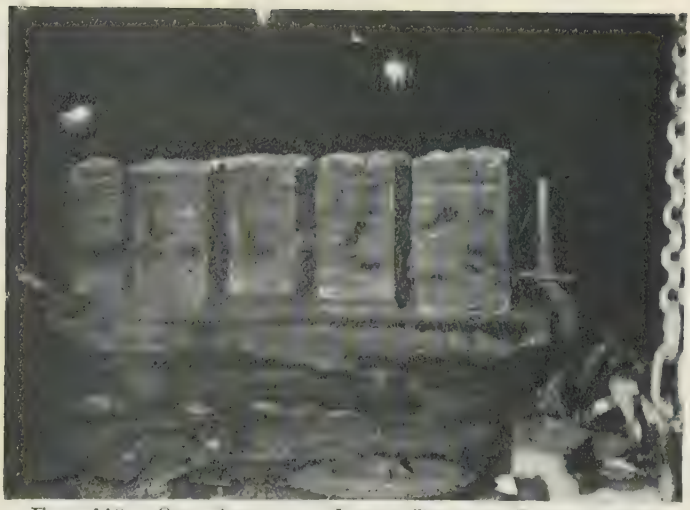


FIG. 119. ONE SIDE OF A LARGE TURBINE CASTING WITH FEEDERS ATTACHED.

FIG. 120.—THE OTHER SIDE OF THE SAME CASTING.

Fig. 121.—Large Valve for the same Turbine Set.

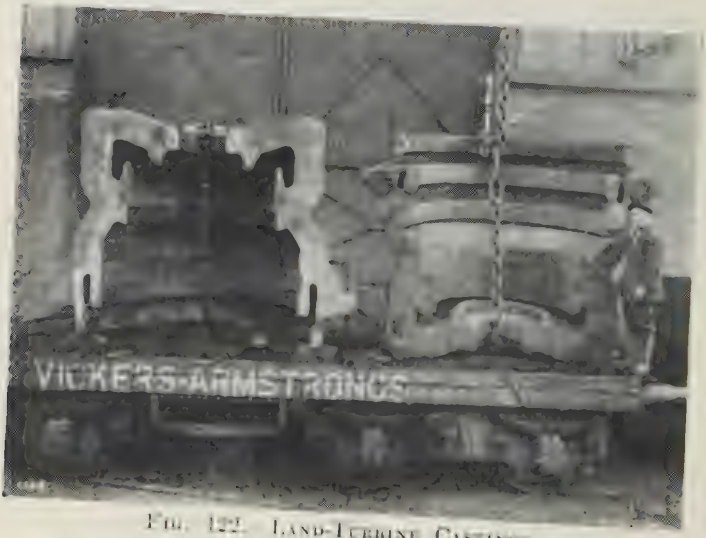


Fig. 122. Land-Turbine Castings.

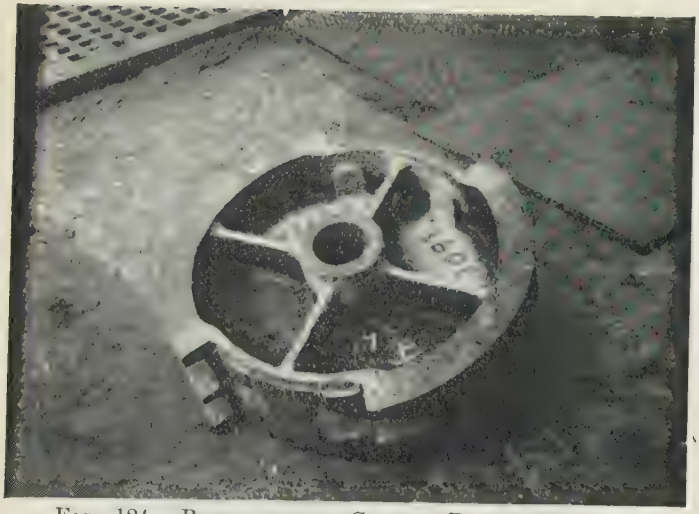


FIG. 124.—BLOWHOLES IN CASTING RUN AT POSITION MARKED (X).

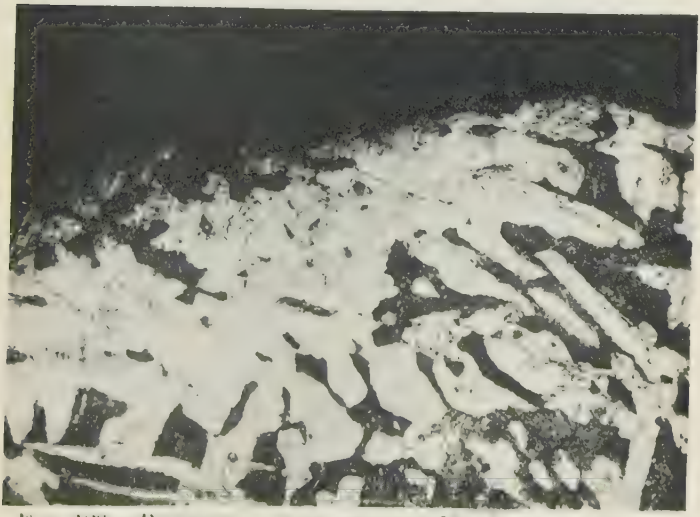


FIG. 126.—BLOWHOLE CAUSED THROUGH MOISTURE IN MOULD.

The many reasons for this defect are scabs on moulds or cores due to moisture, bad vents, or faulty sand, all three items causing the scab. The moulder's term "scab" really means the result of sand breaking away from the mould or core and mixing with the metal. In addition,

Fig. 123.—Blowholes beneath the Feeder Location.

the moulder may carelessly leave dirt in the mould during the closing operations.

Cold Shuts

Another form of defect, viz., what is known as the "cold shut," is seen in Fig. 129, and there is not usually much difficulty in recognising this

particular defect, the general form being as seen here. This defect is chiefly due to cold metal, runners into mould not being sufficiently large or not correctly placed, or excessive use of chaplets. Such a defect is usually recognisable from its appearance, but can easily be confirmed by a microscopic examination of a section. Fig. 130 shows the typical appearance of such a

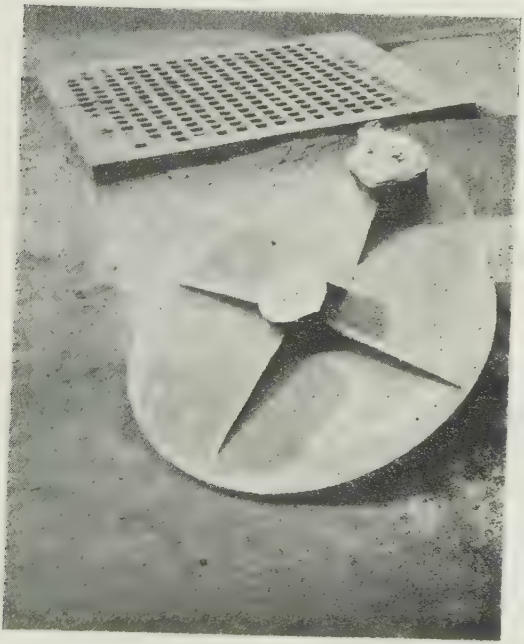


FIG. 125.—ANOTHER EXAMPLE OF BLOWHOLE.

defect, a definite line of demarcation being present, where the streams of metal have met, associated with oxide.

Radiography

Defects such as are revealed by ordinary methods of examination are well understood, but when the modern method of X-ray examination is employed, the diagnosis of defects on the

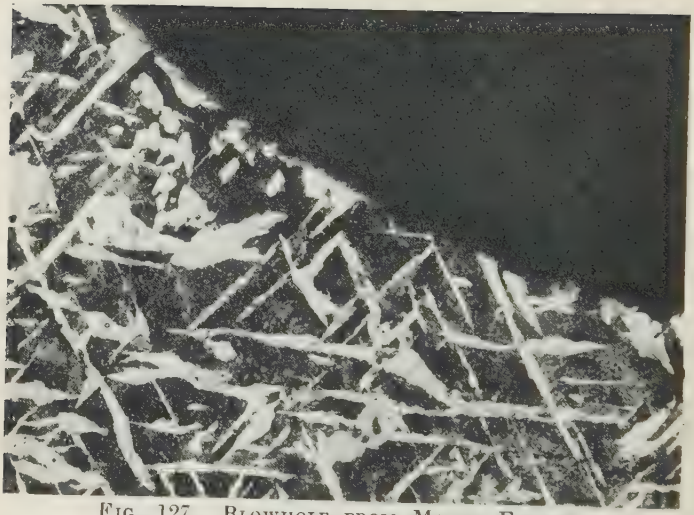


FIG. 127.—BLOWHOLE FROM MOULD FACING.

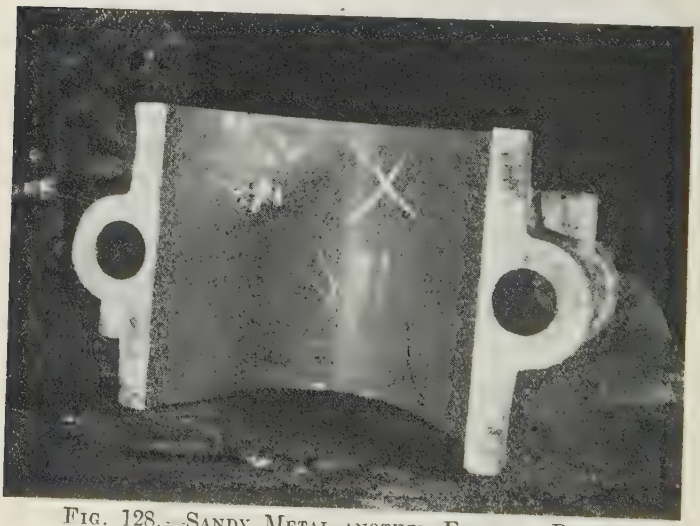


FIG. 128.—SANDY METAL ANOTHER FORM OF DEFECT.

radiograph requires an expert to interpret. By such a method of examination, however, defects may be disclosed in a casting which previously appeared perfectly sound.

It is perhaps fairly safe to say, that only a small proportion of commercially-produced castings would be 100 per cent. perfect under such searching examination, but it is necessary to preserve a calm mind in the face of such results

FIG. 129.—COLD SHUT.

as may be obtained. Such a method of examination, however, if the results are carefully interpreted, can be of the utmost value to all, brief reference having already been made to some typical results. The technique of radiological examination of steel castings is now, thanks to scientific research, at a high level, although the correct interpretation of the negative, as mentioned previously, necessitates specialised skill and experience.

Whilst the use of X-ray and similar methods of examination may appear somewhat futuristic

to some, it is being used fairly extensively in some fields, and its use can be expected to increase as its real value becomes more generally understood and appreciated.

Repairing Steel Castings

Referring now to repairs to steel castings by means of the electric-welding process, a clause is contained in some modern specifications rigidly prohibiting such, even in those instances where

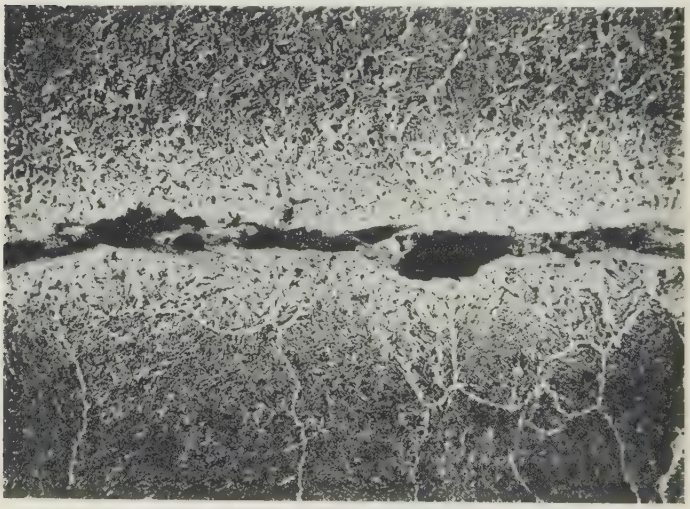


Fig. 130.—Section of Cold Shut. × 20.

defects are purely superficial. The importance of such a proviso and the necessity of searching inspection before and after repair, can be appreciated, when consideration is given to the high stresses entailed in the working of modern plants.

Castings of to-day being designed to give minimum weight, little or no risk at all can be taken where repairs may affect the soundness of the casting. The methods of repairs to castings vary considerably; comprising operations by means of electric welding or acetylene welding.

burning with metal, brazing, soldering plugging or patching.

In those instances of repair where it is considered local stresses may arise as a result of electric welding, or burning, a low-temperature anneal is carried out to ensure the removal of such stresses, prior to the casting being finished machined. A minor defect in a casting gives rise to lengthy discussion when a proposal to repair is put forward to determine whether the casting should be repaired or rejected. The overseer has a most responsible duty, and efficient inspection and fair decision may only be given in conjunction with a knowledge of those methods by which castings are manufactured, coupled with an understanding of the service they are to give.

Briefly, it may be said that the degree to

FIG. 131.—MICROGRAPH OF BURNED TEST-BAR.

which a casting is defective, serious or otherwise, can only be determined by those with a detailed knowledge of the methods under which it was made. It is the opinion of a large number that the process of electric welding, done with careful control is perfectly reliable, even on the body of castings for high temperature and high-pressure turbines, providing the castings are afterwards heat-treated to remove strain. The same remarks apply to the operation known as "burning" on iron castings, which is carried out by pouring molten metal into a mould made round the defective part.

In this connection a test was recently carried out by breaking a bar from a pair of test-bars, cast together, afterwards jointing the broken bar by the method described. The two bars were then machined, and on testing in the usual

manner identical results were obtained, namely, 15.2 tons per sq. in. The micrograph, Fig. 131, shows the excellent nature of the junction between the parent metal and that used to create the join.

It is rather difficult to understand the hesitancy shown by some people in accepting such processes as have been mentioned in the case of minor and superficial repairs. It is the general opinion amongst those connected with the manufacture of castings, that more confidence should be displayed where defects are not unduly serious. Sound material and good design go hand in hand in any reliable structure, and the vast strides that have been made in recent years in all fields are a result of co-operation of all concerned in the manufacture of a casting, viz., designer, patternmaker, moulder and metallurgist.

Conclusion

Regarding the art of moulding and coremaking and its relation to science, mechanical and metallurgical, it is true that progress has been achieved in accelerated production and in the composition of metals, which latter has greatly increased strength values. The improvement of the metallurgical side has been enormous of recent years, and, due to decreased scantlings, as a result the foundryman's problems have seriously increased.

Nevertheless, art and science in industry exist apart as well as co-ordinate, and an important factor towards the production of sound castings of intricate design is the wealth of technique acquired by craftsmen over years of experience.

It is now widely recognised that still further co-ordination is necessary, and this is reflected in some of the very able Papers recently given by members of the Institute, and also in the educational schemes which have been recently arranged for in Sheffield, and by the British Cast Iron Research Association; it is hoped these schemes will thoroughly combine the practical and scientific side and make both as one.

Both appear to be excellent schemes on paper, and it is to be hoped they are going to produce a class of executives for the profession educated on all the points that have been referred to. If so, it is considered that the foundrymen of the future are going to get a great opportunity of producing the perfect casting so much required in modern engineering, in which lightness of design, due to the great advance in materials, has become such an essential feature.

The authors desire to say again in conclusion that it has been their intention to deal with the various subjects from as practical a standpoint as possible, and venture to hope that it will be a contribution interesting to all in the foundry and to engineers, who use the products therefrom. They take this opportunity of thanking the Directors of Messrs. Vickers-Armstrongs, Limited, especially Sir Charles Craven and Mr. J. Callander, for their kind permission to use the illustrations, without which the authors would not have been able to attempt so effectively to explain the various points relating to the subject.

Communication

Mr. J. G. Pearce wrote that he heard this Paper delivered at Manchester and was greatly impressed with its value. Few foundrymen have had, or will have, the opportunity of presenting a Paper covering such a range, including as it does iron and steel castings, special alloys and non-ferrous metals in green sand, dry sand and loam and in a wide variety of sizes. It was one of the most practical Papers ever given to the Institute and for many years would be a mine of information for students, teachers of founding and practical men. The illustrations were an important feature. The Paper shows what could be done by a combination of wide practical experience and technical control.

He was naturally especially interested in the comparative results of the heat-resisting irons introduced by the B.C.I.R.A., Silal and Nicrosilal, especially as the comparison iron was what in all probability would be regarded as a good type of heat-resisting iron.

PAPERS PRESENTED TO THE BRANCHES.

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EXPERIENCES IN THE MANUFACTURE OF HIGH GRADE AND HIGH DUTY ALLOY IRON CASTINGS

By P. A. RUSSELL, B.Sc. (Member)

There have been many Papers on the properties and advantages of these irons, but few have dealt with them, particularly the alloy irons, from the producers' point of view. The experiences given, cover the production of castings for general engineering purposes, particularly machine tools, and, in the case of the alloy irons, for many general applications, mostly of a non-repetitive nature.

It should be understood at the outset that in referring to high grade irons, the Paper does not deal with the special high tensile and similar irons of the inoculated type, but with the production of engineering cast irons with tensile strengths from 12 tons to 18 tons sq. in., the principal qualities required being soundness, fine graphite size and uniformity.

The production of this class of casting requires an iron in which the carbon is below, often well below, the eutectic point. Several formulæ have been put forward to determine the carbon content of the eutectic, and the author has found that the simple one of $C = 4.3 - \frac{Si + P}{3}$ will work quite well; thus an iron with 2 per cent. silicon and 1 per cent. phosphorus has about 3.3 per cent. carbon at eutectic composition. The further the carbon is below this composition, the better the iron is for soundness,

strength, uniformity of hardness, etc. In producing these irons the usual methods of silicon control are necessary, but these are too well known to be enlarged upon here. The author is familiar with the work of the Institute's Cast Iron Sub-Committee on total carbon and phosphorus, but, for economic reasons, most of the practice with which this Paper deals has been developed around irons with phosphorus between 0.7 and 1.0 per cent.

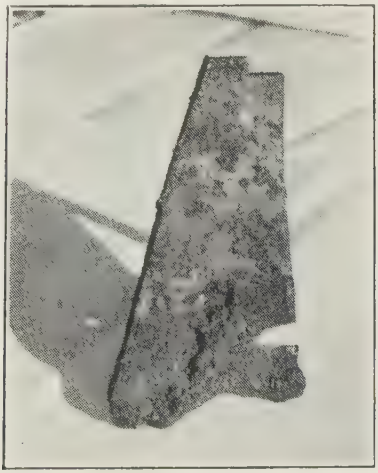

FIG. 1.—PIECE OF STEEL RECOVERED FROM CUPOLA.

To produce high grade cast iron, carbon control must be exercised along with the usual silicon control. Most of the ordinary brands of pig-iron, whether phosphoric or not, as produced in the modern high-output blast furnace, have carbon rather in excess of the eutectic amount, and it is necessary to reduce this by means of special pig-irons, refined irons, steel, or a combination of these. The two former materials are comparatively expensive, so that steel is used in the cupola wherever possible.

Cupola Conditions

It is proposed to deal first with the production of irons that have carbon of about or just under the eutectic amount, and have physical properties rather in excess of those required to meet B.S.I. Grade A Specification 321. These irons can be poured into moulds that are made

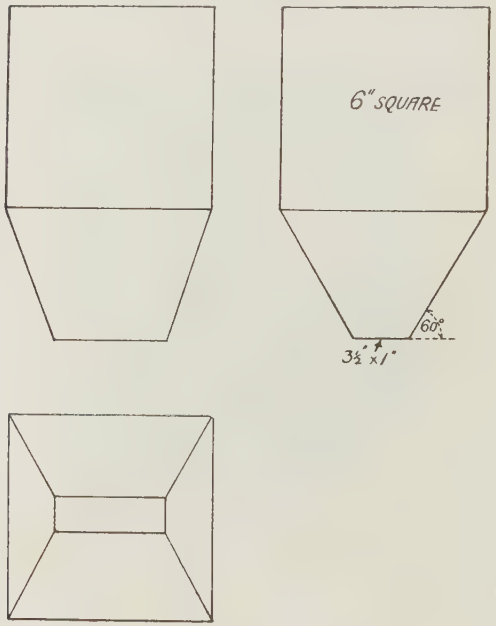

Fig. 2.—Feeder Riser.

in the ordinary foundry routine and require no special feeding.

The amount of steel that can be used in the cupola for this purpose depends on two factors:—(1) the cupola conditions, and (2) the composition of the balance of the charge. The conditions required in a cupola to ensure minimum carbon pick-up are well known and can be

summarised as quick melting with the correct amount of air, and quick tapping. The effect of the various types of coke or carbon pick-up are not yet thoroughly understood, but hard cokes seem to give the best results, probably owing to their quick melting properties. If the cupola be operating under these conditions then the amount of steel that can be used for this class of casting is quite small. Personal experience shows that 10 to 12 per cent. is the limit. If special precautions are taken to ensure a

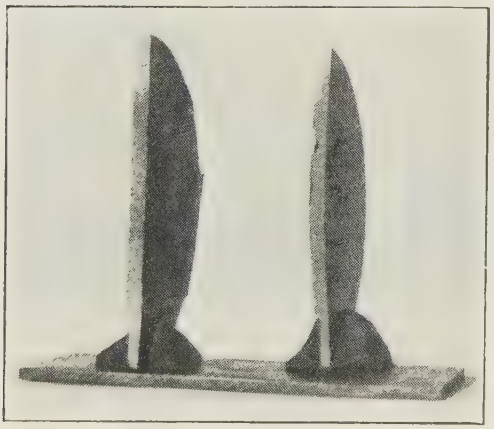

Fig. 3.—Light Casting with (Right) and without (Left) a 2 per cent. Nickel Addition.

high carbon-pick-up, then larger amounts can be used.

Naturally, the second factor, that of the composition of the balance of the charge, is important. Irons containing carbon much in excess of the eutectic amount can carry a fair amount of steel, whereas irons with carbon under the eutectic amount cannot be used with steel for this class of casting.

To obtain tensile strengths of over 14 tons per sq. in. and Brinell hardnesses of over 200,

in sections 1 in. thick and over, it is necessary that the carbon should be reduced distinctly below the eutectic amount. To produce this class of iron from steel and ordinary irons requires a cupola that is very well preheated and closely controlled for air supply. Excess air produces oxidation and consequent increase of shrinkage troubles, and insufficient air gives slow melting. If the cupola be controlled to give its theoretical melting rate, then the air supply is about right. The amount of steel required to produce these results varies from 20 to 50 per cent., according to the carbon reduction required. The manganese content of the accompanying pig-iron must be kept high.

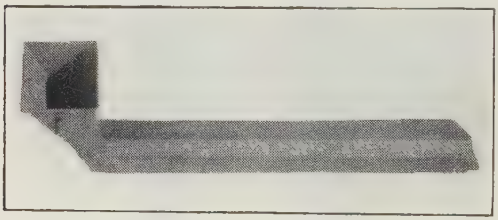

FIG. 4.—ALLOY SHUTE.

Bought scrap iron of unknown source cannot be used owing to its uncertain composition.

In addition, great care must be taken to ensure that the different parts of the charge are adequately mixed in the well or receiver of the furnace before tapping. The constituent parts of the charge melt at different rates, particularly when phosphoric irons are used in the mixture. Thus, if the iron be tapped in small quantities and the furnace frequently drained, then an irregular product is bound to result. As it is desirable to get the metal out of contact with coke as quickly as possible, this is apt to become a vicious circle when working a cupola without a receiver.

Carburisation of Steel

The author has been investigating the mechanism of the melting of steel in the cupola, and microscopic examination of the edge of a piece of steel that was just starting to melt shows that the carburisation of the steel does not commence before melting. The piece of steel from which this was taken is shown in Fig. 1, the analysis showing the carbon to be 0.14 per cent.

The risks and irregularities consequent upon the use of large amounts of steel often make this process much more expensive than would appear at first sight, and it then becomes a matter of economics as to whether special or refined iron is used instead of steel or not. Thus, the greater cost of these materials is often counterbalanced by the greater certainty of obtaining a regular product. If these special irons be used, care is still required in melting to prevent excessive carbon pick-up, for the benefits of low-carbon irons may be entirely neutralised by bad remelting.

An alternative that is becoming increasingly popular is for the foundry to make its own refined pig-iron from charges high in steel. The use of soda ash facilitates this process, as sulphur pick-up can be counteracted.

Feeding Low-Carbon Irons

With these low-carbon irons the troubles of the producers of castings are greatly increased. The apparent solidification shrinkage of these irons is much greater than that of ordinary grey iron. This is largely due to the lesser amount and smaller size of graphite formed. Thus, the foundry practice has to approximate more to that of malleable than ordinary grey-iron practice. Personal experience has been that risers of the self-feeding type are one of the most satisfactory ways of dealing with this. If the risers can be transformed into runners by means of strainer heads, so much the better, as the hottest metal is in the feeder, where it should be. A typical riser is shown in Fig. 2. If it

is necessary to run the casting near the top, then feeder knobs should be placed at the back of the ingate. Unless feeding by the runner is attempted, the runner should be placed at the thinnest part of the casting, if practicable.

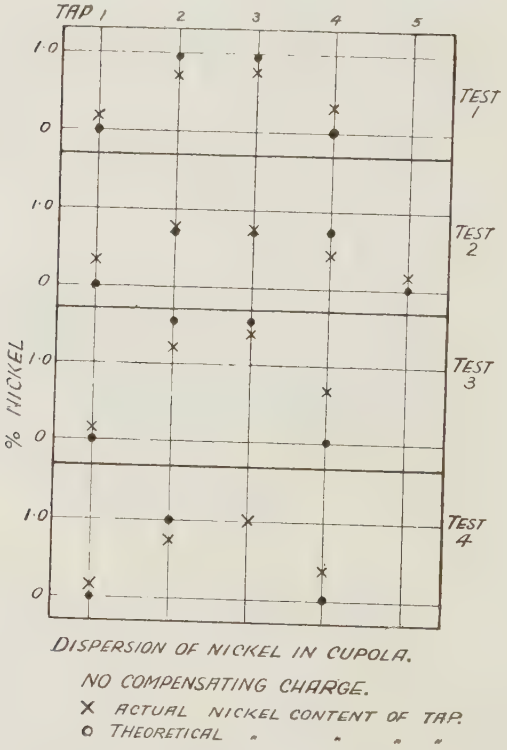

Fig. 5.—Dispersion of Nickel in Cupola Tests, 1 to 4.

Dry-sand moulds are to be preferred for the following reasons: (1) The high pouring temperature required for this class of iron tends to fuse the face of green-sand moulds; (2) their rigidity helps to divert the expansion due to the

formation of graphite to an inward direction, instead of an outward direction as in the case of green-sand moulds, thus to some extent counteracting the shrinkage, and (3) troubles due to the concentration of shrinkage at certain points of the casting due to localised gas pres-

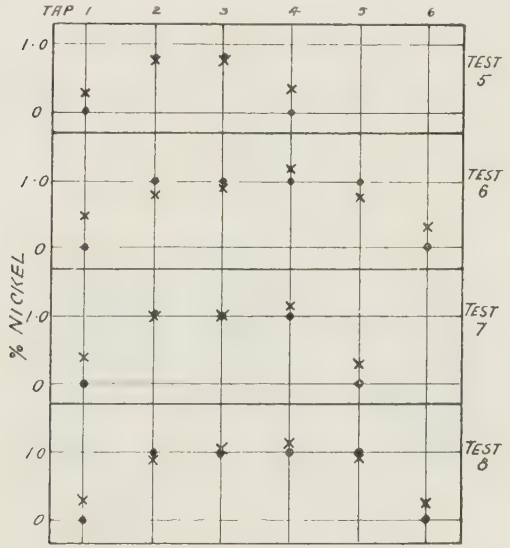

FIG. 6.—DISPERSION OF NICKEL IN CUPOLA TESTS, 5 TO 8.

sure are reduced. For the same reason adequate venting of the cores and moulds is essential.

Personal experience is that denseners are still necessary to compensate for irregularities of section, though the lower the carbon is below the eutectic point the less these are required. To summarise this—as the carbon passes from amounts above the eutectic points to amounts

below, the shrinkage changes from an internal porosity to external sinking.

Production of Alloyed Cast Irons

To turn to the production of alloy cast irons, it is proposed to deal first with the production of irons with low alloy contents, in which the amount of alloy is insufficient to change the iron from its usual ferritic or pearlitic condition. The most common alloying elements are nickel and chromium. Many other elements are now being used, but personal experience to date is confined to these two, with the exception of silicon, which can be regarded as an alloy in such irons as Silal, and copper, which is incidental to Ni-Resist.

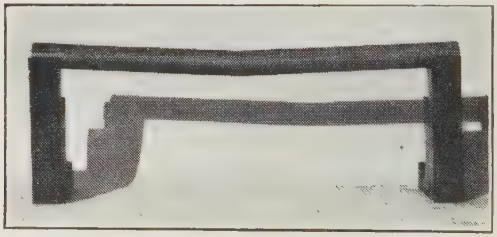

Fig. 7.—Transverse Test-Bar in Ni-Resist.

It is not sought to discourse upon the advantages of the use of nickel and chromium, but nickel and chromium together have been found very useful in producing fine grain, uniformity of high hardness, good wearing properties and strength, or separately give graphitising or chilling effects.

It is best to use nickel and chromium together wherever possible, in the usual proportion of 3:1, as it is then unnecessary to effect the silicon reduction that is involved in the use of nickel alone. Silicon reduction usually means carbon increase, which is undesirable. On the other hand, nickel can be used as a softener where exceptional conditions make this desir-

able. For instance, one occasionally gets a call for extremely thin castings, which are chilled if cast in 2.5 per cent. silicon iron, which is the highest silicon normally run in the author's foundries. These castings are made from this 2.5 per cent. silicon iron, with 2 per cent. ladle addition of nickel. The result is shown in Fig. 3. Similarly a cheap but effective heat-

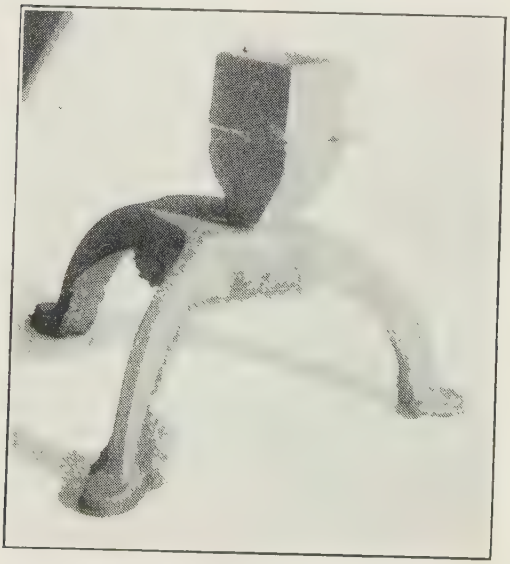

Fig. 8.—Three-Legged Stand in Ni-Resist. Casting with Feeders Attached.

resisting iron can be made by adding sufficient chromium to a low-silicon iron to cause the castings to run white.

Introduction of Alloys

The first essential in the creation of alloy cast irons is the production of a good base iron. This is one of the reasons why this subject has been dealt with rather fully in the first part of the Paper, at the risk of repeating what is

fairly common knowledge. Then comes the question of how to introduce the alloys. The available methods are: (1) Ladle additions; (2) additions to the cupola charge of alloys in a concentrated form, and (3) use of pig-iron containing the necessary amount of alloys.

Ladle additions have the great attraction of certainty, but the disadvantage of cooling the liquid metal. The use of concentrated alloys in the cupola is to be avoided wherever possible and the remelting of iron to give the exact composition required is the best way, providing that the quantity required is sufficient and the

FIG. 9.—VALVE IN NI-RESIST.
CASTINGS WITH FEEDERS ATTACHED.

expense of preparing or buying the material is warranted.

Very satisfactory results can be obtained by using ladle additions. A high tapping temperature is required, and the alloys should be in as concentrated a form as possible, compatible with low fusion point. Personally, the author uses the standard " F " nickel shot and 70 per cent. ferro-chrome (4 to 6 per cent. C.), powdered to pass 40-mesh sieve. To ensure that the correct amount of base iron is tapped to suit the predetermined amount of alloy, it is desirable that

the ladle should be suspended from a weighing machine. A shute of the form illustrated in Fig. 4 is used, and the alloys introduced into the stream of metal coming down the spout, at a point as near the tap hole as possible, preferably at a point where there is some turbulence in the stream. This is to be preferred to the fixed-hopper method, as the alloys can be directed into the stream. The alloys are introduced into the first half of the tap. By these methods up to $2\frac{1}{2}$ per cent. of nickel and 0.8 per cent. of chromium can be added.

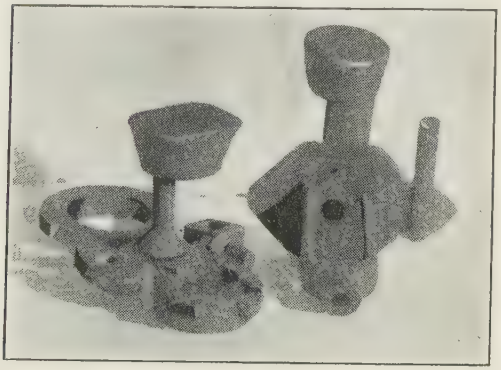

Fig. 10.—Group of Small Parts in Ni-Resist. Castings with Feeders Attached.

The author has never found any difficulty from the lack of diffusion of the alloys. But he must repeat that the metal must be tapped at a very good super-heat to carry such a large amount of addition, which is over 4 per cent. of the total and incurs considerable temperature reduction. Nickel is more easily introduced than chromium, and can be added without any allowance for loss. The fineness of the ferro-chrome powder renders it very liable to be carried away by hot-air currents, and it tends to float on the surface of the metal in the ladle in cakes. These should be broken up by a stirrer, or preferably pushed under the descending stream of

metal. The chromium loss may vary from 5 to 15 per cent. of the amount added.

It is preferable to introduce as much of the alloys as possible into the cupola charge by means of re-melted runner heads, etc. Thus, the ladle additions are reduced to the amount necessary to alloy the new metal part of the charge and make up for chromium losses in remelting the runners. Also, if chromium additions above

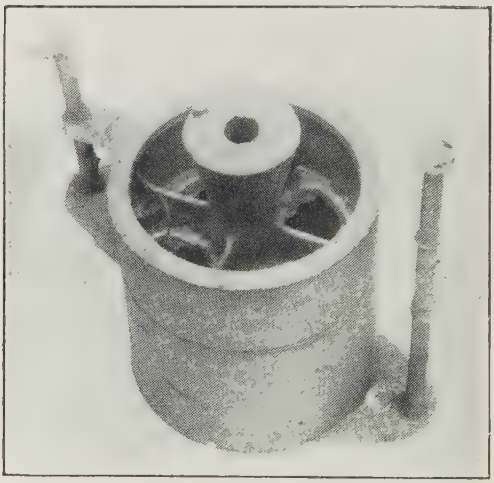

Fig. 11.—Drum in Ni-Resist.
Casting with Feeders Attached.

0.5 per cent. are required, the best way is to use a chromium-bearing pig in the charge.

If the whole of a cupola blow be devoted to the production of one class of alloy iron, there are no particular difficulties in securing an accurate product, but if only a part of the melt consists of alloy work, then extra care is required. If the castings to be produced be fairly heavy, the alloy metal can be melted first, followed by the ordinary blow, or *vice versa*. Some people blow the furnace right down, drain the furnace, put

on a fresh bed of coke and start again. This is not so easy as it sounds.

Separating the Charges in Cupola Practice

Wherever possible, it is preferable to run alloy irons in a separate melt, grading the different types into one another in the same way as ordinary irons. In one recent melt the author produced five different qualities of alloy irons from two base mixtures, making the differences by ladle additions.

If the castings are light and the quantity

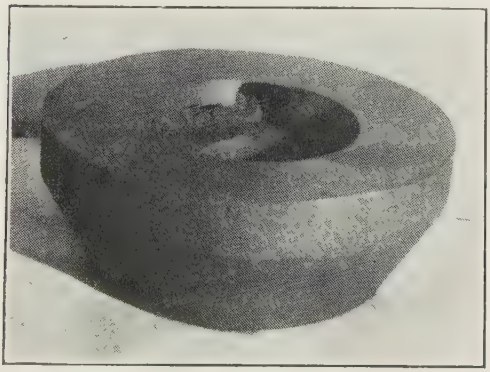

FIG. 12.—NI-RESIST FEEDER, BORED OUT, SHOWING SHRINKAGE.

insufficient to warrant a separate melt, sufficiently hot metal cannot be produced at the beginning of the melt to avoid a fair amount of discard. Thus, it is necessary to introduce the alloy charges after a certain amount of ordinary iron has been run through the furnace. Then the difficulty of the separation of the charges becomes acute. The complete separation of the charges in a cupola, without serious interruption of the melt, is impossible. With regard to ordinary irons, this is best overcome by the gradual up

or down grading of the mixture. There is always an intermediate grade between two types, but with proper discretion this can usually be dealt with. When alloy irons are used in which the whole or part of the alloy content is in the cupola charge, there is bound to be some of the alloy appearing in the preceding and succeeding taps of metal, with a consequent deficiency in the alloy taps. Fig. 5 makes this clear. In this instance, large quantities of excess coke were used in an attempt to separate the metals, but was of little help. In this example a quantity of ordinary iron

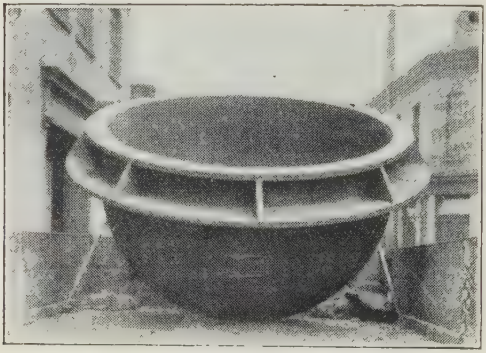

FIG. 13.—HEAT-RESISTING POT IN NICKEL-CHROME CAST IRON.

was run first, which was used to obtain a general warming-up of the furnace and ladles, and could be used for unimportant castings. Accurate timing and weighing of all metal tapped from the furnace was used to control this. The effect of an error in timing is shown in Test 2, where the metal was tapped too late, causing the nickel to be concentrated in the earlier taps. The nickel figures shown are irrespective of ladle additions.

Then a charge of metal was introduced before and after the alloy charges, which was in the nature of a charge for producing refined iron,

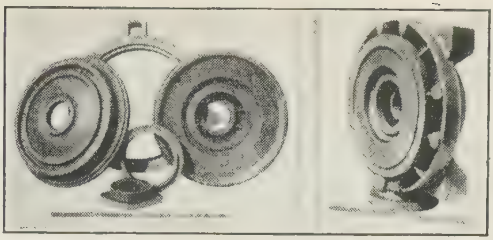

Fig. 14.—Pump Parts in Austenitic Cast Iron.

Fig. 15.—Stoker Links in Austenitic Cast Iron.

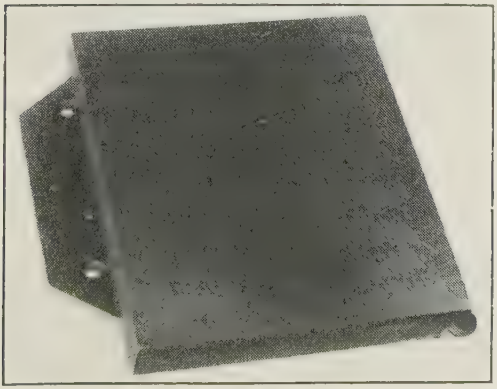

Fig. 16.—Hotplate in Nickel-Chrome Cast Iron.

and this absorbed the wandering alloy. This refined iron was then used on the following day as part of the alloy-iron charge, its alloy content being neglected in the calculations, and the deficiency was replaced. The results of using this method are shown in Fig. 6.

If only small quantities of alloy iron be required, and a suitable base iron is being run in the ordinary cupola melt, these can be made

Fig. 17.—Valve in Austenitic Cast Iron.

quite satisfactorily by ladle additions alone, within the limits given above. The runners so produced can be used up on occasions where larger quantities are required, or, if the nickel and chromium be balanced, used up in the ordinary standard iron. This latter involves the loss of the value of the alloys in the runners. With regard to the preparation of moulds for this class of alloy work, no alteration need be made in the practice given above for high-grade irons.

Other Alloyed Cast Irons

To turn now to the alloy irons in which the alloy introduced is sufficient to modify the basic structure of the metals. Those of which personal experience has been had are as follow:— (1) Irons with nickel about 3.5 per cent., which are made martensitic by heat-treatment. These can be produced by ladle addition methods, providing there is at least 1 per cent. of nickel in the metal tapped from the cupola. (2) Irons

Fig. 18.—Cam, in Heat-treated Nickel-Chrome Cast Iron.

that are martensitic as cast (Ni 4.0 to 4.5 per cent., Cr 1.5 per cent.). Personal experience with this has only been with crucible melting, which presents no special problems, but it would appear that cupola-melting methods on the lines given above could be adapted to suit this metal. The low carbon and low silicon sometimes employed for this class of alloy iron necessitates adequate feeding and precautions against cracking, similar to malleable methods. (3) Austenitic cast irons of the Ni-Resist type (Ni 14 to 16

per cent. Cu, 5 to 6 per cent., Cr 2 to 5 per cent.).

The author has produced this material (No. 3) by both crucible and cupola methods. Dealing with the cupola first, it is considered essential to devote the whole of a cupola melt exclusively

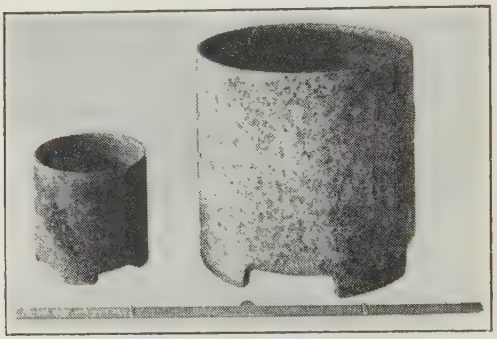

Fig. 19.—Carburising Pots in Austenitic Cast Iron.

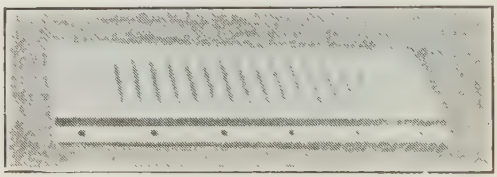

Fig. 20.—Press Tool Block in Nickel-Chrome Cast Iron.

to the production of this iron. The cupola should be thoroughly well preheated, and oxidising blast conditions avoided. The charge is made up of a suitable base iron, together with nickel-copper-chromium pig; Monel metal can be used, but no personal experience of this has been had. Remelt up to 50 per cent. of the

charge may be carried. Low-carbon base iron is not necessary, and no steel is required in the charge. If chromium above the amount given by the Ni-Cu-Cr pig be required, then a chromium-bearing pig should be used and ladle additions avoided.

Silicon and manganese losses are rather heavy —about 15 per cent.—and sulphur gains considerable. Chromium losses are also consider-

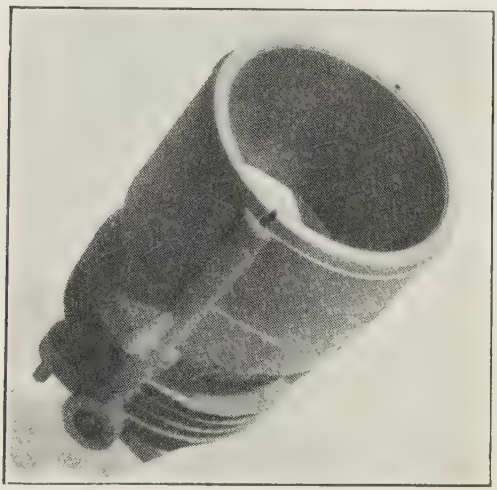

FIG. 21.—CYLINDER IN NICKEL-CHROME CAST IRON.

able, and vary with the concentration of chromium in the charge, high concentrations giving high losses. Nickel and copper losses should not occur, but under bad melting conditions, some of the melted Ni-Cu-Cr pig will freeze as it comes into contact with the cold air at the tuyeres, and so will never reach the well of the furnace.

For crucible melting, personal experience is that silicon, manganese and carbon losses and

sulphur gains occur when melting Ni-Resist scrap, so that allowances have to be made for these to almost the same extent as in cupola practice.

Casting Austenitic Cast Irons

The foundry technique for pouring austenitic irons requires a great deal of attention to be

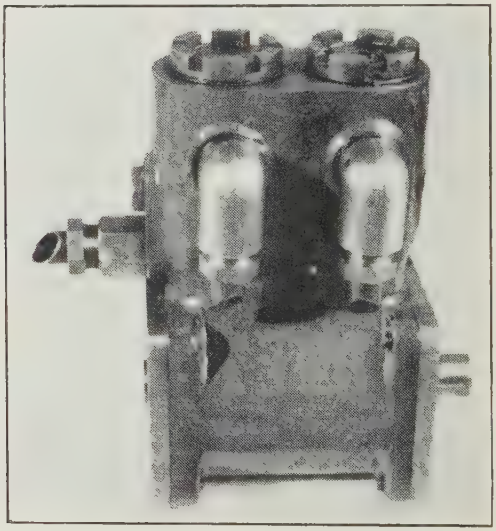

Fig. 22.—Valve for Hydraulic Saw in Nickel-Chrome Cast Iron.

paid to feeding arrangements. An extension of the methods given earlier in this Paper is required, and the feeders require to be heavier and less necked. This, together with the toughness of the material, frequently makes the removal of these risers a difficult proposition. This toughness is illustrated in Fig. 7, which shows a $\frac{7}{8}$-in. dia. test-bar just beginning to crack in a transverse test.

Denseners can be used to accelerate the cooling of parts that cannot be reached by a feeder, but denseners alone on castings that have any considerable masses of metal are useless. They may give surface soundness, but the inside of the casting will be hopelessly "drawn." A judicious arrangement of denseners in the heavy sections in the bottom of the mould and feeders on the heavy sections in the top of the mould is the most satisfactory way. The cross-sectional area of the feeder should be greater than that of the heaviest part of the casting. High-chromium austenitic irons need more feeding than low-chromium ones, presumably on account of the lesser amount of graphite formed.

The moulds are usually in dry sand for safety and ease of running thin sections. Dry-sand feeders are more effective than green-sand, and every effort should be made to keep the feeder as hot as possible, so that it is the last part to solidify. The metal has little "life" and should be poured as hot and as quickly as possible. Figs. 8 to 12 show methods of running and feeding austenitic iron castings.

Castings of thin sections or with high chromium should be heat-treated to give ready machinability. This treatment is very simple and consists of soaking at 850 deg. C. for $\frac{1}{4}$ to 1 hr. according to the thickness of the job and then cooling in the furnace or in air, preferably the latter. The carbides are thus broken down and the ductility of the metal much improved. No reference has been made to the production of Silal or Nicro-Silal, as these are not of such general interest.

Finally, Figs. 13 to 22 show a few illustrations of castings made of alloy iron produced by the methods outlined in this Paper.

It is thought that the foregoing remarks go to prove that the production of alloy cast irons is very largely a specialist's job. The more alloy iron of any one type that can be produced from one melt, the more satisfactory and regular

the product is likely to be. Personal opinion is that a new branch of the foundry industry is developing to deal with alloy irons. Each branch of the industry, such as rain-water goods, stove-grate, automobile and engineering castings has its own particular problems, both technical and economic, and these have been best solved by specialisation.

In conclusion the author wishes to thank his co-directors of S. Russell & Sons, Limited, for permission to produce this Paper, and the staff for their assistance in its preparation.

DISCUSSION

Heat-Treatment of "Ni-Resist" Castings

Dr. T. B. Crow, opening the discussion, called attention to the surprisingly large loss in most of the metalloids and a gain in sulphur, and asked if the sulphur gain were due to accidental contact with coke. Further, he asked for particulars of the heat-treatment of the high-chromium "Ni-Resist" casting.

Mr. P. A. Russell replied that the proportion of nickel to chromium in the martensitic as-cast product varied very much with the job. He had mentioned the proportions as roughly 4 to 5 per cent. nickel and up to 1.5 per cent. chromium, depending very much on the hardness required and the amount of machining to be done. If there had to be a lot of machining, the chromium content must be kept lower.

With regard to the sulphur gain during crucible melting, he thought that some of it was due to accidental contact with coke, but he believed that it may be due largely to the affinity of nickel for sulphur. He had had experience of remelting nickel cast irons both austenitic and of low nickel content, in a crucible, and much to his surprise he had found that the sulphur had gradually built up until the graphitising effect of the nickel was more than counteracted by the chilling effect of the sulphur.

A week previously he had been more definite than he had been since concerning the heat-treatment of high-chromium austenitic irons; he had some work in progress in his department, and so far had found that, by heating to 850 deg., and allowing a sufficient time, according to the section of the casting, to ensure that the temperature was 850 deg. right through it, and then cooling in air, he had obtained the best results. But apparently there was some reduction of tensile strength due to that treatment.

Carburisation of Steel in the Cupola

Mr. A. E. Peace (President, East Midlands Branch) was surprised by Mr. Russell's remark concerning the absence of carburisation of steel in a cupola before it actually melted. He had never heard that stated before, and had never known anyone produce evidence to substantiate it, and, therefore, he asked if Mr. Russell had checked that result by evidence other than that of the particular case quoted. One knew definitely that steel would readily absorb carbon, and he could only conceive that if Mr. Russell had met the case where the steel had not absorbed carbon before melting, it must be due to the gas conditions in the cupola being definitely oxidising.

Mr. Peace joined issue with Mr. Russell in connection with the external sinking and internal porosity. It had been stated that a change of carbon from above the eutectic point to below the eutectic point caused a change from external sinking to internal porosity. But Mr. Peace could not really see the difference between the phenomena of external sinking and internal porosity; they were both matters of shrinkage, in the one case the shrinkage being outside the casting, whereas in the other one a defective zone was left inside the casting. Perhaps Mr. Russell would explain the point more fully and could give some assurance that he was right.

One had thought Mr. Russell was going to say that ladle additions were quite satisfactory, but

he had qualified that statement by saying that one must weigh the ladle. He was definitely right there, because it seemed impossible to judge the content of metal in a ladle. But unless a foundry were operating to a considerable extent on alloy metals, it would appear that the weighing of the ladles would result in interference with production.

Two Types of Shrinkage

Mr. Russell said that although he had perhaps jumped to conclusions with regard to the absence of carburisation of steel in the cupola before it melted, he had confirmed the phenomenon by a second piece of steel, from the same blow as the first, and which was retrieved from the dump of a cupola which had been blown down. There was a deficiency of metal—the steel had not all melted. Admittedly the conditions in the cupola would be oxidising, because the phenomenon had occurred at the end of the blow. Candidly, he had expected to find that the steel was partly carburised, but in this instance it was not—and perhaps that was why the steel did not melt.

Discussing external sinking and internal porosity, he said it seemed there were two distinct manifestations of the property of shrinkage—the one internal and the other external. If one bored a hole in iron having carbon in excess of the eutectic amount, one found an open grain and definite voids in the centre; but if one ran in the same manner a cast of iron having carbon below the eutectic amount, the casting would be internally sound, but would be sunken externally. There seemed to be a very definite change from one characteristic to the other.

He felt very strongly about the necessity for weighing the ladle when making alloy additions. One could not produce alloy irons accurately otherwise.

Low Carburisation of Steel Confirmed

Mr. C. H. Kain (Past-President, London Branch) recalled some work he had carried out

four or five years ago on the melting of steel in the cupola, and said that undoubtedly the steel did not absorb much carbon in the solid state. He believed that Field had also carried out some work in that connection ten years ago, as published in the "Foundry Trade Journal." In his own work Mr. Kain had made a series of blows and had deliberately dropped the cupola half-way through the blow, and in every case the steel which had not melted had not absorbed carbon. He had also taken samples of metal from another steel melt by means of a ladle through the tuyeres and, surprisingly, the samples contained something less than 2 per cent. of carbon—about 1.6 per cent.; the carbon pick-up was very much less than was commonly thought.

Mr. Kain took exception to Mr. Russell's statement that when dealing with low-carbon high-quality iron it was necessary to use dry-sand moulding, because if green sand were used there would be local fusion by reason of the high pouring temperature. He pointed out that it was common practice to use green sand for steel castings, which were poured at even higher temperatures, and he could not see that the drying of the mould made the sand any more refractory; if the green sand would fuse he did not see why the dry sand should not also.

Finally, Mr. Kain asked if Mr. Russell had found any modification of the basic structure of the iron in the casting resulting from the use of denseners. Whilst they helped in securing soundness, they definitely caused a very considerable modification of the structure of the casting. Although the casting might still be grey, the structure in the portion adjacent to the densener was quite different from that in other portions; the carbon had a different form and the matrix of the iron was quite different, and where machining or any wear occurred the behaviour of the iron adjacent to the densener was different from its behaviour in parts away from the densener.

Dry-Sand Moulds and Refractories

Mr. Russell, dealing with the question of the use of dry-sand moulds, said that refractoriness was only one consideration. Admittedly, the refractoriness was not increased by drying, but it was improved by the application of a protective coating by the wet-blacking process. His company did not operate a steelfoundry, so that, as this practice had been developed from grey-iron practice, the drying methods he had mentioned had become necessary.

He had not carried out any micro-work on the effect of chills and denseners, but from the point of view of subsequent machining and wearing, he had seen very little traces of their effect, except, of course, when a densener was so heavy that it changed the combined carbon content, in which case, of course, one would expect to see a brighter and smoother surface. But he had used denseners on all sorts of castings which were subsequently machined, and could not detect the places in which those denseners were used. He agreed that if a chilling effect were obtained the structure was modified.

Overcoming Porosity

Mr. M. Russell (Scottish Branch) was glad to hear the author's statement that nickel alone did not produce a homogeneous structure. Dealing with porosity, he said that it occurred sometimes in the drag portion of castings, especially where there was $\frac{3}{16}$ in. or $\frac{1}{4}$ in. of machining, but did not occur throughout the casting. He asked if the author could suggest a remedy for it. In some castings the difficulty was overcome by adopting a centrifugal method of gating. The trouble was pronounced in chromium cast iron. He did not think that denseners or chills provided a remedy.

Mr. P. A. Russell said that the Report of the Sub-Committee to which he had referred dealt very largely with direct porosity, and the remedy lay in the metal control, by reducing the carbon and properly balancing the silicon. The

low-silicon irons were definitely better, and that was where the value of nickel came in, in enabling the founder to run low-silicon iron and secure machinability without consequent increase of graphite size.

Austenitic Cast Irons

Mr. F. Hudson (Scottish Branch), discussing the production of austenitic cast iron, said that his firm had used a quantity of "Ni-resist" for making valves for all applications. He was particularly interested in the method described in the Paper for running valves, but his firm did not use such heavy risers as those described; they could make valves satisfactorily by using a far smaller riser if they cast the valves on end instead of on the flat. When they had first made "Ni-resist" they had used dry sand, but had discontinued that practice and found that they obtained as good or better castings in green-sand moulds. They had also tried cupola melting but had discontinued it and were concentrating entirely upon crucible melting for "Ni-resist," because they had found definitely that when that metal was produced from a crucible it had far less liquid shrinkage than when produced from the cupola. Another important point was that in the production of "Ni-resist" castings free from porosity he had found that he could not use a large percentage of scrap in the mixture. As a result, his firm tried to separate the types of castings into two grades—those which could be produced easily and which had an uniform section, and those which were more difficult to produce and had varying sections. In the one case they used practically all scrap and in the other case they used practically new metal. Castings in the former were small rams and pump plungers, etc., which were plain cylindrical castings, whereas those in the latter category were miscellaneous castings required for valves, etc.

He asked if the crucible furnace used by Mr. Russell was coke-fired. His own firm used a crucible melt and obtained very much less loss

in the crucible than in the cupola; indeed, he had only tried to use the cupola once but was so staggered by the melting losses that he had not used it since. It was also his experience that in crucible melting there was a tendency to lower carbons; but in his view that was an advantage, because the iron had a lesser range of liquid shrinkage and was not liable to suffer porosity in changes of section.

More Confirmation on Carburisation

Discussing the melting of steel in the cupola, Mr. Hudson recalled a Paper he had read to the Newcastle Branch of the Institute in 1924,* showing the effect of melting conditions in the cupola, and said there was no doubt at all that carbon was not absorbed in the steel in a cupola before the steel was melted. In that Paper he had given a full series of micro sections. Probably that was the Paper to which Mr. Kain had referred, because Mr. Hudson did not think that Field had published any work in that direction.

Mr. Russell was particularly interested in the suggestion to cast valves on end instead of on the flat, and said he would certainly try it. His firm were essentially jobbing founders, so that they had to use customers' patterns, a fact which did increase their problems. Probably they could make things better from their own point of view if they had control of the pattern-making. Valves were among the castings which gave him least trouble—he played for "safety first"; these castings were expensive to produce, and the aim was to try to achieve success initially rather than to try to save an hour or two on production. If scrap were produced from them, there was difficulty in breaking it up; indeed, he kept one large casting to demonstrate toughness, and for the benefit of visitors pieces were broken from it by hammering.

Possibly green sand would give better results than dry sand when casting austenitic iron; but the dry sand was used from the point of view of safety.

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* "Proceedings, I.B.F." Vol. XVIII, p. 401.

Remelt and Shrinkage

It was interesting to hear that less shrinkage occurred when crucible melting was adopted as compared with cupola melting. The shrinkage problem in "Ni-Resist" was very largely wrapped up with the question of re-melt. He had tried to find out why that should be so, but could not, so that he had reached no definite conclusion; but he agreed that the more re-melt introduced, the greater were the difficulties. He had now arrived at a satisfactory correction for re-melting, taking into account the silicon and other losses to which he had referred, and was using re-melt up to 50 per cent. (It was pointed out in the Paper that re-melt up to 50 per cent. was used in the cupola charge.) That did help, because it gave consistency. If one made up from new materials, one was likely to get base iron melting at one time and N.C.C. melting at another.

When he had first tried cupola melting, he had obtained bad results, as had Mr. Hudson, but nowadays he was getting definitely regular results. These results depended largely on thoroughly preheating the cupola. The crucible furnace he used was coke fired.

Dr. Crow asked if Mr. Russell knew more or less accurately the temperature of alloys such as "Ni-Resist" as they left the crucible, and whether he attempted to control it by the time factor or whether he used optical or other pyrometers.

Mr. Russell replied that he was not a great believer in optical pyrometers. His aim always was to get the temperature of the metal as high as possible—and he had never been able to get it hotter than he had wanted it. One of the reasons why he preferred the cupola to the crucible furnace was that he could get the metal hotter in the cupola.

Mr. G. L. Harbach asked if there were not a greater tendency to blowholes as well as shrinkage troubles in low-carbon irons.

He also asked what was the total-carbon content of "Ni-Resist." To obtain 3 per cent. T.C. in the final metal when using about 25 per cent. of non-ferrous metals obviously required 75 per cent. of 0.4 per cent. carbon, which usually could only be obtained with a hematite iron, with its very coarse graphite and low phosphorus.

Another question was whether annealing was recommended for "Ni-Resist" castings of very thin section. Theoretically, one would expect that the quicker cooling of the "Ni-Resist" should make the austenite more likely, and, therefore, one would expect it to be non-magnetic. Crucible-melted centrifugally-cast liners in "Ni-Resist" were almost invariably magnetic and unmachinable, but the annealing process corrected that and restored the non-magnetic condition. But by reason of the fact that they were magnetic as-cast, one was inclined to be very suspicious that the mixture had gone wrong.

Mr. Russell agreed that with low-carbon irons, particularly when melted under oxidising conditions, there was a greater tendency to the formation of oxide holes in the castings. The total carbon amounted usually to 2.8 or 3 per cent. in "Ni-Resist." The use of Ni-Cu-Cr pig, which contained very little carbon, did reduce the total carbon, but a little was picked up in the cupola. He had endeavoured to maintain the carbon as high as possible, from the point of view of reducing external shrinkage; but, having heard Mr. Hudson's remarks, he would try keeping it lower, in order to see whether the castings produced would be sounder internally.

The magnetic properties present before annealing were due to chromium carbides formed during the rapid cooling, he believed, these carbides being magnetic. The heat-treatment was necessary, not for the transformation of Martensite to austenite, but purely for the breaking down of the carbides of chromium that were formed. When the carbon went into the austenitic state, the magnetic properties were lost.

Spin Runners Reduce Porosity

Mr. A. R. Bartlett (Past-President, London Branch) proposed a vote of thanks to Mr. Russell for his very practical Paper.

Discussing his own experience, Mr. Bartlett said it had been the custom at his works some years ago to make some of the small important castings from metal melted in the crucible, because the carbon pick-up was small and a better product was obtained. But since the crucible furnaces were taken away and he had been working with cupolas only, he had found that by the judicious addition of steel the carbon content was kept low; a proportion of steel was used in practically every mixture.

Porosity had been seriously reduced by means of a spin runner, which gave an even distribution of all the products of the melt. For example, in the case of a circular casting a runner was provided all the way round and there was a riser at the far end of the runner; the line of travel of the metal was reversed by the ingates, which should be as numerous as possible so that the metal would be entering all round the casting. This method of running had proved to be very satisfactory.

Speaking of melting special alloy irons, Mr. Bartlett agreed that it was essential to preheat the cupola thoroughly. Some years ago he had tried to melt special alloy irons in a cupola after other irons had been melted, and also before other irons were melted, the purpose being to effect economy. His experience had indicated, however, that it was essential to run a cupola for the high-alloy irons only, and not to run other irons in the cupola, either before or after.

Rapid Fall in Temperature

There was also a very definite limit as to how much metal could be melted, run into one ladle and poured successfully, owing to the rapid loss of temperature. One difficulty in connection with the use of the optical pyrometer was that if it were read by different individuals the readings would differ; but he used an optical pyrometer and read it himself, so that he felt satisfied that he was getting comparative figures.

The loss of temperature in the alloy irons was so rapid that he could not melt more than 2 tons and pour it successfully into small castings. The largest of the castings he had in mind weighed about 10 cwts., and some weighed only 7 or 8 lbs., and they were poured from the same ladle. In order to overcome the difficulties of pouring he had tried to put as many of the small castings as possible into one moulding box, connecting them by means of runners in order to give the metal the opportunity to get through. The metal used was an iron carrying 4.5 per cent. nickel, 1.5 per cent. chromium about 2.5 to 2.75 per cent. carbon, 0.6 or 0.65 per cent. silicon, 0.1 per cent. sulphur, 0.1 per cent. or a little less phosphorus, 0.1 per cent. cobalt and about 0.2 per cent. copper. A Brinell hardness of 760 was aimed at, and invariably that, or something very near it, was attained. The metallic and other losses in the cupola were rather high; the silicon loss was in the region of 20 per cent. in the smallest cupola at the works, and when a larger cupola was used the loss was even greater. The loss of manganese was 30 per cent.; there was a sulphur pick-up, though it was not serious; there was no loss of nickel (indeed, there was a percentage gain as compared with the elements in respect of which there were losses); the chromium loss was about 15 per cent.

Dr. A. B. Everest, seconding the vote of thanks, commented upon Mr. Russell's statement that little had been published yet with regard to the practical side of the manufacture of special irons. He suggested that the reason was that where difficulties had arisen, and it had proved necessary to develop special methods of running and pouring castings, these methods had perhaps been regarded as trade secrets. Therefore, he expressed the opinion that the meeting owed a great debt of gratitude to Messrs. S. Russell & Sons for allowing Mr. Russell to publish all the information he had presented. He also said that the meeting was greatly indebted to Mr. Russell for the excellent manner in which he had prepared and presented his Paper, and had subsequently handled the discussion.

Scottish Branch.

DEFECTS IN IRON CASTINGS: THEIR CAUSE AND CURE

By T. Tyrie (Associate Member)

In taking up the subject of defective castings, it is done in the full knowledge that considerable difference of opinion exists amongst foundrymen and metallurgists regarding the nature and cause of many of the troubles which arise in the production of iron castings. Since uniformity of opinion is a very desirable factor in the drive towards eliminating these bogeys, it is thought wise to present the results of recent critical examinations of several types of defects, in the hope that they may lead to a better understanding of the nature and cause of such defects, and, having established these, the elimination becomes only a matter of time.

It is to be clearly understood that the scope of the present Paper is confined more or less to small- and medium-weight general engineering castings, such as are produced on a repetition basis, but with few exceptions the general finding can be applied to heavy work.

Defects may arise primarily from one or more of four possible sources: —Metal, sand, moulding practice and design. Extended they include:—

(1) Faulty composition and melting of the metal; a lack of fluidity due to composition, temperature, gas inclusion; incorrect casting temperature. All these are a function of the metal.

(2) The sand used for the mould or core may be of unsuitable composition; insufficiently permeable to gases; lacking in strength; insufficiently refractory; or too rigid to yield to the contraction of the metal whilst cooling. All these are a function of the sand.

(3) More often the defects are due to small errors in the patterns, such as faulty jointing, giving rise to wrong positions for runners and risers, or cores may be so placed that proper venting is hard to obtain. The actual size, shape and position of runners and risers may be faulty and productive of mould erosion, gas trapping, metal dulling, and the consequent improper run-

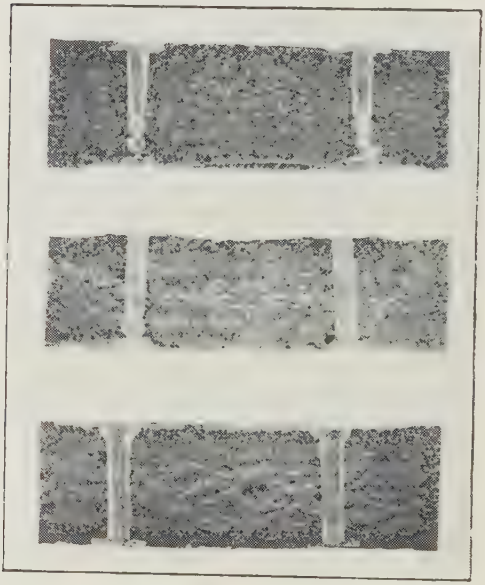


Fig. 1.—Sulphur Prints, showing Chaplets in Section Blocks.

ning and cold shuts. Risers may be too small and so far removed from heavy sections that feeding is impossible. Tackle may be in bad repair, especially moulding-box bushes and pins, giving rise to sided castings and cross-joints; moulds may be closed end for end; moulds may be crushed or knocked against whilst sitting ready to cast, giving rise to sand holes and dirty

castings. All these are a function of moulding practice and care in the foundry.

(4) Design of casting may be such as to disregard totally the fundamental principles of the moulder's art and the metal in use, in which case the production of sound castings is attended with the greatest difficulty. This is a function of the designer or engineer, and is beyond the scope of the present Paper.

For convenience of treatment, it has been decided to classify the defects met with in foundry practice in accordance with the scheme in use in the author's employ, as follow:—(1) Mould

Fig. 2.—Blow-hole in Meter Cylinder caused by Poor-quality Wax Vent.

and core faults, embracing crushing, scabbing, cores breaking and run-outs; (2) sided and cross-joints, embracing cores lifting, faulty closing, worn tackle, etc.; (3) blow holes; (4) sand holes; (5) slag holes; (6) metal faults, embracing drawn and porous castings, contraction cracks, cold shuts, gas holes and oxidised metal; and (7) bad work, embracing closing of moulds wrongly, short pours, interrupted pours, etc.

It will not be possible in the space available to consider each type in detail, nor, indeed, is such necessary, since some defects are so readily recognised and the cause and cure so obvious to

the intelligent foundryman that no useful purpose is to be served by going into detail here. Rather will it be the objective to scan but lightly these obvious defects and direct attention to a fuller consideration of a few particular types which, upon the surface, often

FIG. 3.—INCLUSIONS IN TOP SURFACE BLOW-HOLE.

appear so simple yet are so hard to overcome because their real nature has not been recognised.

Mould and Core Faults

Crushing is more common in dry sand than in green sand, since the latter is more plastic and will yield to any misfit in the mould or core

parts. A clearance should be pared off the joints of all moulds, and, when dealing with deep patterns, care should be exercised to trim back the joints which tend to become pulled up slightly when withdrawing the pattern.

Scabbing in a green-sand mould may arise from sand being too wet, mould rammed too hard or insufficient venting. Particular care should be exercised not to ram projecting parts of a mould too hard, and the point of the rammer should not be allowed to come closer to the pattern than from $1\frac{1}{4}$ to $1\frac{1}{2}$ in., since otherwise the result will almost inevitably be a series of small scabs. The vent wire should also be used freely on projecting parts of the mould. Scabbing can

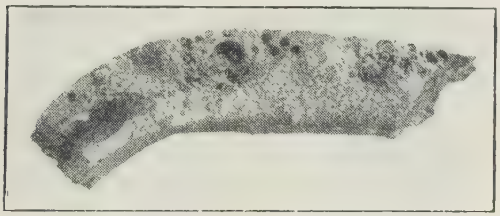


FIG. 4.—ANOTHER EXAMPLE OF A SURFACE BLOW-HOLE.

also be caused by excessive use of the "swab" for pattern drawing, and it is advisable to prevent this practice as much as possible. In dry-sand work, scabs are almost always due to improper venting, and it is advisable to use sand with good venting properties, or, alternatively, a sand which evolves little gas on casting.

Cores Breaking

Cores breaking are more often the fault of the coremaker than the moulder. Cores should be properly strengthened with irons wherever necessary, and it must be realised that good cores cannot be made from sand, which in itself is of poor quality. Another core fault which has been observed arises directly from the use

of oil sand. This is a tendency for oil-sand cores to soften and yield to the pressure of the molten metal whilst casting, if such cores have been allowed to sit in a green-sand mould for extended periods, such as over the week-end. The remedy for this is, of course, perfectly obvious.

Fig. 5.—Nail-shaped Inclusion in Top Left-Hand Corner of Right Section.

Run-outs arise through the pressure of the molten metal lifting the cope, and the remedies in increasing the weights holding the top part down or altering the method of securing it. Many run-outs occur without any lifting of the cope, but by the metal creeping along joints and ultimately pouring out at the box joints. The precautions required to overcome this trouble are everyday practice, and a waster

on this account is perfectly avoidable in the majority of cases.

Sided and Cross Joints

Sided castings are the direct results of two faults: (*a*) Cores lifting and (*b*) faulty positioning of cores in the mould, whereby the divisioning of the metal section is rendered uneven.

The former fault, *i.e.*, cores lifting, is more often a complaint against the patternmaker than the moulder, on account of insufficient prints on the patterns. This is false economy, as the few pence saved in the pattern shop are wiped

Fig. 6.—Sectional View of an Inclusion.

out by the additional work for the moulder, with the risk of a bad casting.

Chaplets are often of great service in preventing cores from lifting, but the proper use of these should be well known if porosity is to be avoided. It is surprising how many moulders are under the impression that chaplets actually melt and become diffused throughout the mass of metal poured into the mould. It is not necessary nor, indeed desirable that the chaplet should melt completely, since its doing so would undo the purpose for which it has been used. Nevertheless, it is an advantage to have incipient fusion to ensure complete welding of

the chaplet and the base metal. The secret of this is, of course, absolute cleanliness and freedom from oxidation, under which conditions there should be no trouble from porosity or blowing. Fig. 1 shows the sulphur prints obtained from sectioning three blocks having chaplets cast-in, in such a manner as to section the chaplets. In one case the chaplet was cleaned from rust, etc., by pickling in acid and thoroughly washing and drying. In another, the chaplet used was coated with red lead, and in the third case a tinned chaplet was employed. It was found that best results were obtained from the pickled chaplet, whilst the tinned one was next and the red-lead-coated one last. There is, however, little to choose between the pickled chaplet and the tinned one, and in view of the expense involved in pickling, along with the trouble of storing in a dry place to ensure that the cleaned goods will not rust up again, the tinned chaplet is, on the whole, the more profitable.

The latter fault, *i.e.*, faulty positioning of cores, is inexcusable except in the heaviest and most intricate of work, where the positioning of cores at times assumes a difficult aspect. The usual method of gauging metal sections around cores by means of clay stamps is universally practised and for intricate work in many places cores are now being set to specially-designed gauges.

It should also be added in this connection that under certain conditions where oil sand is being used there is a tendency for cores to sag slightly whilst sitting in the green state prior to baking, and unless the finished cores are carefully gauged before being issued to the moulder some trouble is likely to arise under this heading.

Cross joints are generally the result of slackness in moulding box pins and holes. The fault is inexcusable, but may be attributed to both moulder and master. In general work where moulding boxes are not jig-drilled and bushed a certain amount of clearance in the pin holes is necessary. The common practice for ensuring

correct registering of cope and drag are sufficiently serviceable if properly applied. On the other hand, if the management will provide well-made boxes for use in the foundry the possibility of risks being taken is removed and this class of trouble eliminated to a large extent. Especially is this necessary in plate- and machine-moulding practice where wear on the box pins and pin-holes should be checked occasionally, as also the tolerance allowed in moulding machine pins and pattern-plate holes.

Fig. 7.—Sulphur Print of the Inclusions shown in Fig. 6.

Blow-holes

Blow-holes have usually a smooth, shiny and bluish surface, and to a large extent are caused by gas coming from cores which are not thoroughly dried or are not properly vented. Occasionally blowing occurs even when such precautions have been observed, and in such cases the trouble may be due to metal getting into the core vent and causing a choke, very often resulting in the metal blowing violently out of the runner and riser. Fig. 2 illustrates a meter cylinder which shows a blow-hole on the top

In this case the trouble has arisen through the use of core-vent wax of inferior quality and which did not permit of a clear vent being obtained after baking, in the jacketed core which forms the by-pass waterway seen on the side of

FIG. 8.—MICROSECTION OF THE NAIL-LIKE INCLUSION SHOWN IN FIG. 5. × 100.

the casting. Another source of blow-holes has been brought to light as a result of careful investigations of this prevalent trouble, and it is proposed to treat the subject in rather a fuller manner. The defect comprises blow-holes surrounding metallic inclusions in the form of

pellets, and it is contended the trouble arises out of faulty pouring in conjunction with metal on the dull side. In Figs. 3 and 4 it will be seen that metallic inclusions are embedded in a blow-hole just on the top surface of the cast-

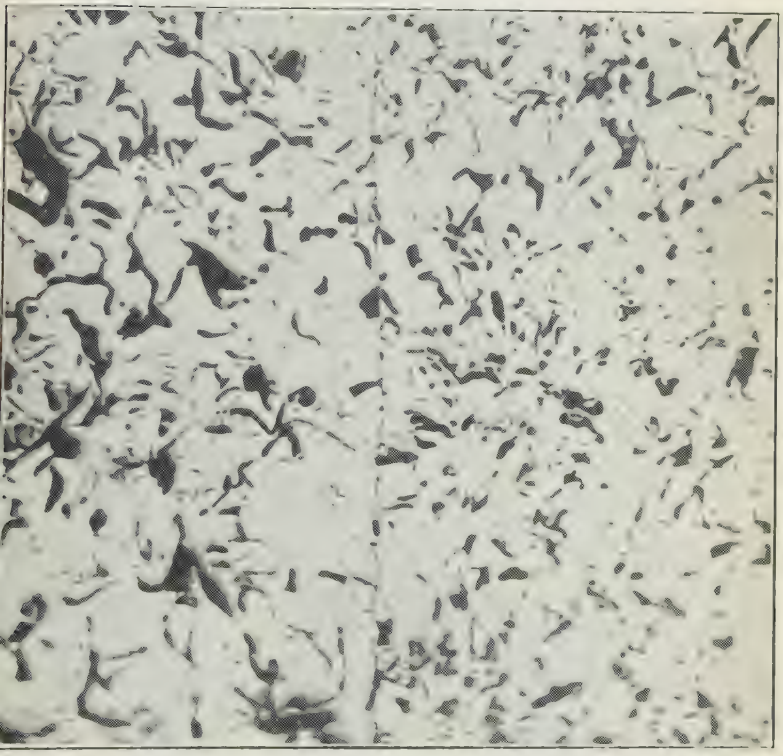


Fig. 9.—Microsection of the Real Inclusion shown in Fig. 5. × 100.

ing, whilst Fig. 5 shows an interesting inclusion in the shape of a nail which may be seen on the top left-hand corner of the section. Fig. 6 shows a sectional view of an inclusion and Fig. 7 is a reproduction of sulphur prints from the section of Fig. 6 and a similar sound section

below the defect in the same casting. It is to be clearly understood that the inclusions here considered always appear near the surface of a casting and are not to be confused with the

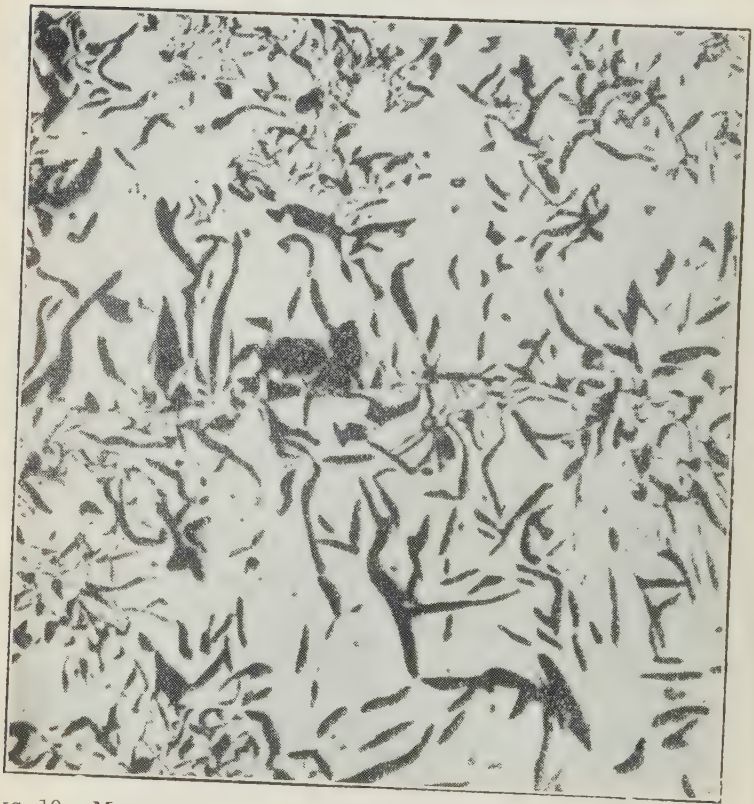


FIG. 10.—MICROSECTION OF A VALVE SHOWING CO-EXISTENCE OF TWO SETS OF CONDITIONS. × 100.

segregation globules occasionally observed in gas pockets in the interior and final sections of a casting to solidify.

Close examination of the sulphur prints reveals an outstanding difference in the appearance of

the metal which forms the pellet compared with that of the main body of the casting. A small amount of slag may be seen in the vicinity of the pellet, and the general appearance of both sulphur prints leads to the conclusion that the

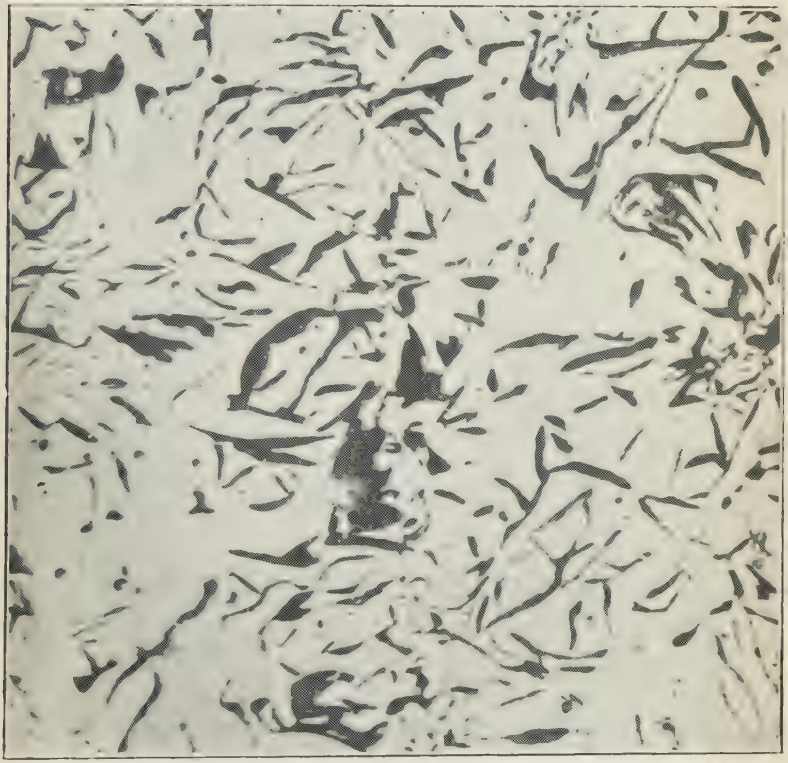


Fig. 11.—Microsection of Fig. 1, showing Complete Welding of Bead Inclusion and Base Metal.

metal temperature was not quite so high as it might have been, although there is no reason to believe that it was too cold.

Micro-sections were next cut from each specimen in such a way as to include an inclusion

along with the base metal, and these were examined in the polished condition at 100 dias. Fig. 8 shows the section illustrated in Fig. 5, in which was seen the nail-like inclusion. The section is very interesting, as no bond is apparent between the inclusion and the main body of metal. Furthermore, a disturbance has occurred in the neighbourhood of the inclusion which has resulted in a separation of the main body of metal itself, as evidenced in the right-hand portion of the illustration. That this is a division of the main metal and not another inclusion is clearly evident from the similarity in the metal, whereas the difference between the inclusion and the main body is very marked. The inclusion shows small curly graphite, suggesting rapid cooling with formation of a chilled iron which has subsequently undergone slight annealing whilst slowly cooled in proximity with the body of metal around it, whereas the base metal, by virtue of its relative bulk, has undergone relatively slow cooling and exhibits the usual graphite-flake formation. A consideration of the conditions shown in Fig. 5 and the present one leads to the assumption that the inclusion is the result of a dribble of metal getting down the pouring gate and solidifying prior to casting proper taking place.

Fig. 9 shows a section through the bead inclusion previously shown in Fig. 5. Here again a distinct line of demarcation exists between the inclusion and the base metal, but in this instance there has been no great disturbance in the mould as a result of the inclusion. The dividing line is scarcely visible, and but for the discontinuity of the graphite formations and the difference in form in the two sections, the inclusion might almost be considered as welded on to the base metal. These divergencies, however, amply justify the assumption that the pellet was in existence as such prior to being surrounded by molten iron, and the fact that no blowing has resulted is due to the condition of the skin of the inclusion. More will be said on that point later.

Fig. 10 is taken from another valve, and has been chosen to show the co-existence of two sets of conditions. On the left-hand side can be seen a line of demarcation between the inclusion which forms the upper part of the picture and the lower part formed by the base metal. But as the eye travels from left to right the line gets more obscure, until finally it disappears in a complete rosette of graphite. The curly graphite of the inclusion and the plate graphite of the base metal still show the difference in the condition of the metals, but at their junction a tendency towards fusion is evident, and has, in fact, actually occurred in the neighbourhood of the rosette-like graphite patch. It may be added that examination of the section along the line of division, but extending farther to the right, confirms this, as no difference in structure is ultimately visible.

The above has illustrated two sets of conditions, namely, an inclusion with no bond whatever between itself and the main body of the casting, and an inclusion which is partly welded to the base metal. Fig. 11 provides an example, drawn from Fig. 1, of a third set of conditions, namely, a complete welding of the bead inclusion and the base metal. The left-hand side of the picture shows the bead inclusion, whilst the right-hand side shows the base metal. In the middle is clearly seen a band of graphite flakes common to both sections and formed by the fusion of the bead and consequent diffusion of the two metals.

Interim Summaries

The inclusions in every case have a different structure from the base metal, as evidenced by the micro-sections and sulphur prints; they may or may not give rise to disturbances in the mould, and they may or may not be partially or totally fused to the base metal. It would appear that these inclusions are present prior to pouring, and are a result of faulty pouring, a slight spill in the pouring basin giving rise to the formation of pellets in the mould or, as appears

the case in one of the illustrations, a leaky plug, permitting a thin stream of metal to flow past, creating a dribble. Once formed, the subsequent behaviour of these inclusions depends upon circumstances. If the surface of the inclusion is perfectly free from oxide and slag and the metal normally hot, in all probability the inclusion will weld on to the base metal with no ill-effects. If, on the other hand, the surface is oxidised or coated with slag, no welding is possible, and a disturbance originating at the inclusion and causing a blow-hole is inevitable. It should be mentioned that a careful examination for entrapped slag throughout the entire section in

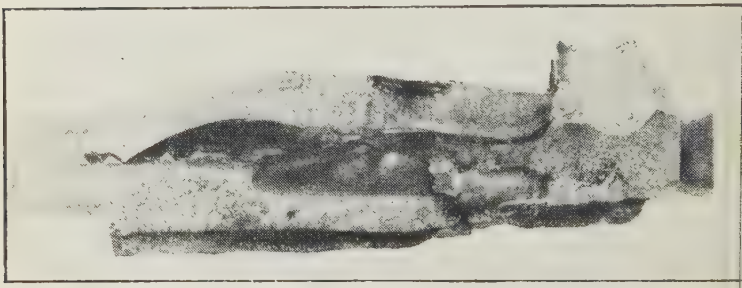


FIG. 12.—INTENTIONAL INCLUSIONS AND BLOW-HOLES PRODUCED IN A VALVE BODY CASTING.

every case considered revealed no trace whatever, except in the vicinity of blow-holes containing a pellet, a fact which is not surprising, since a spill of metal is almost certain to carry a little slag or oxide with it, and this falls into the mould, adhering to the metal.

It is well enough known that dull metal will give rise to many defects, among which may be included blow-holes, and it may be contended the present examples arise from that source. To pursue this point, an attempt was made to produce the defect intentionally. Accordingly, a valve was cast at a temperature of 1,080 deg. C., which is much below normal pouring temperature, and was, in fact, so low that the metal

did not fully come up the risers. In spite of this, the valve, upon examination, was found to be perfectly sound. Continuing this, another cast was made, but just prior to pouring a spill was caused, resulting in a little metal entering the mould. The metal temperature in this case was normal practice, around 1,300 deg. C., and upon examining the casting again, no trace of the pellets was to be found. This shows that a slight spill in itself will not give rise to the de-

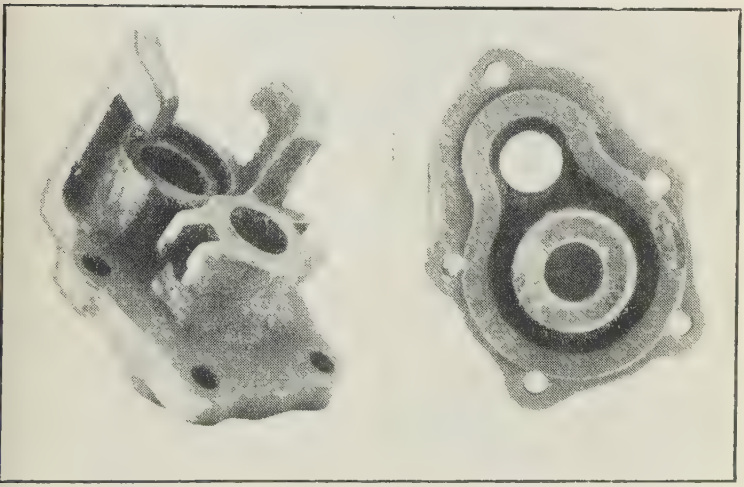


Fig. 13.—Faulty Hydrant Casting.

fect, provided metal of normal casting temperature follows and no slag or oxide is present. A third attempt was more successful, and was conducted as above, except that dull metal was used to follow the spill. In this case definite inclusions and blow-holes were produced, as illustrated in Fig. 12, the valve body being badly blown at several places.

It seems apparent, then, that this type of defect arises out of splashing and pouring with metal which is on the dull side, combined with

the presence of slag or oxide, and a survey of many castings defective due to blow-holes reveals the fact that the majority of them fall under this category rather than under the class of blow-holes due to dampness or venting deficiencies. Care in pouring and good hot metal will eliminate the trouble entirely.

Fig. 13 shows a hydrant cover exhibiting the defect just considered. It was assumed at first that the blow-hole in this case had arisen through a disturbance originating at the surface of the iron chill used to overcome porosity in the heavy section of metal. An examination of the casting, however, revealed the case as identical with those just described, and no useful purpose is to be gained by pursuing the example further. It is possible that blow-holes may arise from faulty chills, but no direct case has come to personal notice.

Sand Holes

This is a very prevalent defect in most foundries, especially where repetition work is practised, and may arise from one or more of many causes, for example:—

(1) Loose sand in the mould itself; adhering to cores or in runner or pouring basin.

(2) Sand washed away or into mould from angles such as edge of down-runner at pouring basin or mould, or from mould corners through edges being weak. Excessive use of the swab for drawing patterns or gate pattern aggravates this.

(3) Entry of dust or sand into mould after it has been closed. This may be caused by carelessness, the mould being knocked or sand dropped into runners from boots when stepping over moulds. Or it may arise from crushes at partings and at core prints or from sand dropped from top parts.

(4) Friability of mould surface due to sand drying out.

(5) Slight scabbing from the mould or core due to improper gating or improper mould manufacture.

(6) Wash of mould facing into pockets due to lack of adhesion between mould facing and sand.

(7) Wash of blacking from cores.

(8) Soft ramming around the base of runner or riser.

(9) Wash from imperfectly baked cores or too much gas evolved causing metal disturbance.

(10) Explosion of gas causing sand to drop.

(11) Improper sand. Low permeability and high strength, or sand too weak. Insufficient strength after drying. Insufficient or too much moisture.

TABLE I.—*Sand Control Test Specification for Light to Medium Weight General Engineering Castings.*

Test.	Green sand.	Dry sand.
Per cent. moisture ..	6.0—7.0	8.0—10.0
Green compression A.F.A. lbs. per sq. in.	4.5—6.0	4.5—6.0
Green permeability A.F.A. Number	60–80	—
Dried compression A.F.A. lbs. per sq. in.	50 minimum	120 minimum
Dried permeability A.F.A. number	—	80 minimum
Gas evolved at 1200 deg. C. cub. ft. per cub. ft. of sand	120 maximum	60 maximum

(12) Vibration communicated by conveyors.

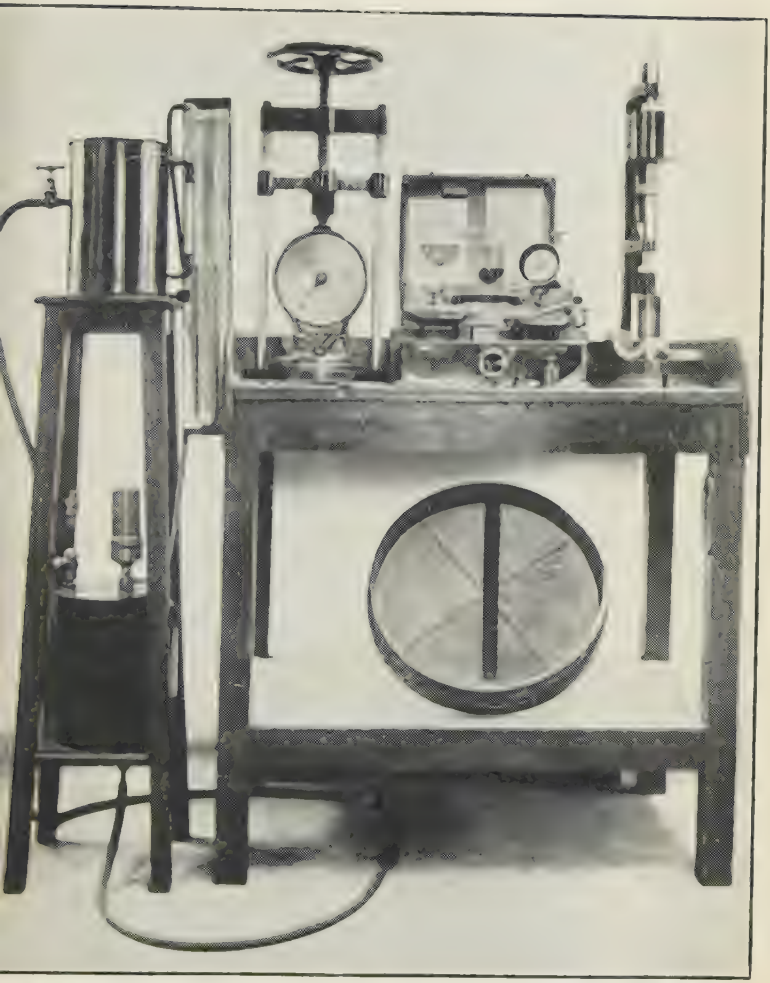
In a great measure the elimination of sand and dirt holes becomes a matter of care on the part of the moulder provided the sand he is supplied with is of a suitable nature for the class of work on hand, and the type of moulding, *i.e.* hand or machine. Table I gives sand control test specifications for light to medium weight general engineering castings, the figures being derived by the use of sand testing apparatus recommended by the Sand and Refractories Sub-committee of the Institute of British Foundrymen and illustrated in Fig. 14. It cannot be too strongly emphasised that control of moulding sand is of almost as great importance in the

production of good castings as is the control of metal, although the former factor is only now being realised, and it is only in controlling the sand that the laboratory can be of service in this matter. Fig. 15 shows in graphical form the dirt loss in greensand work in proportion to the strength of the sand while Fig. 16 shows a similar comparison for dry-sand work; both diagrams taken from the work of Dietert in America.

Given then proper sand for the job the production of castings free from sand holes is largely a matter of supervision. Care should be taken to clean out the mould thoroughly and any loose sand in runner gates and bushes removed. In preference the runner and riser bushes should be made up in the top part before closing the mould since even the finest of workmen may allow a little sand to fall down the gates. The presence of loose sand in the mould has been stressed considerably and quite intentionally because a close examination of many castings showing defects due to sand holes has convinced the author that the majority of these have arisen through loose sand. It is well known that whenever a moulder sees a sand hole in a casting he looks for a bump to indicate from whence the sand causing the hole has dropped or been washed away. In the majority of castings personally examined absolutely no indication of such a drop or break-away could be found which leads to the assertion that loose sand is responsible in these cases and careful work alone can eliminate this.

Slag Holes

This defect may arise from a variety of causes, and its entire elimination is a matter of considerable difficulty, if, indeed, it can be entirely eliminated. The first and obvious source of slag is from the cupola, but under properly-worked conditions the amount of slag flowing into the ladle at the cupola spout should be nil or, at least, very little, and if the metal is as hot as it should be coming from the cupola the sepa-



16.—Sand-Testing Apparatus Recommended by the I.B.F. Sub-Committee on Sand Testing.

ration of entrapped slag will be relatively complete and the slag easily removed.

Another source is the refractory lining of the ladles themselves. The gradual formation of oxide of iron on the ladle walls has the unfortunate effect of lowering the melting point of the refractory used for lining the ladle, and where high-melting temperatures are the practice the net result is the production of slag through the melting of the refractory. It is essential that precautions be taken to prevent this slag from entering the mould, and towards this end it would be an advantage in small work if thin-tinned iron discs, with a few small holes punched

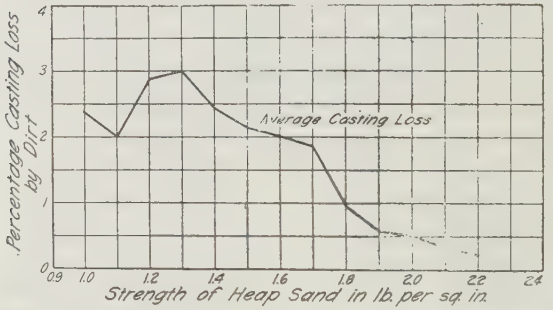


Fig. 15.—Reduction of Dirt Loss by increasing Strength of Heap Sand (Dietert).

in them, be placed over the runner gates in the bush, as shown in Fig. 17. These will resist melting and support the metal long enough to let the basin become filled, and then on melting allow the metal to enter the mould in a clean stream. It is usually just at the beginning of the pour that slag finds its way into the mould. For larger work the gates should be closed with plugs or stoppers, which may be lifted out whenever the basin is full, and it is an advantage to hold the plug, after lifting off the gate, so that it penetrates the surface of the metal, thereby steadying the floating slag and preventing its being sucked down by the rush of metal.

Another step which is advantageous in preventing slag gaining access to the mould is the use of what has been described in America as Tea-spout ladles, whilst Fig. 18 gives an idea of how the ordinary foundry ladle may be easily converted into the tea-spout type with little difficulty, this illustration being taken from a recent issue of "The Foundry."

In spite of such precautions, however, slag

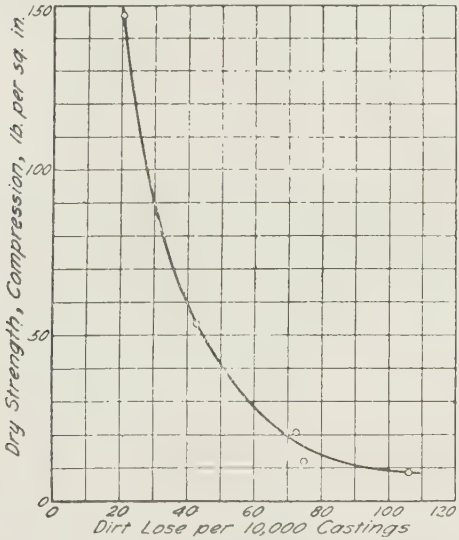


Fig. 16.—Dirt Loss for Dry-Sand Castings (Dietert).

will occur in castings to a small extent, arising from a source over which one can exercise little or no control. Whilst cast iron is cooling from highly-superheated temperatures to that of solidification, reactions occur between included or dissolved iron oxide and the carbon in solution. Furthermore, it is highly probable that reactions occur between the constituents, including iron oxide and the liberated carbon monoxide, as a result of which particles of manganous oxide and silica are liberated, which will,

in turn, unite to form a manganous-silicate slag. That this is probable is borne out by the fact that buttons of slag, composed of a silicate of manganese, have been found at the bottom of pipe cavities in large steel ingots, and it is to be expected that similar inclusions will be frequent in cast iron, especially if the metal is overblown and oxidised. It cannot be doubted that iron oxide is often produced in cupola melting, and the control of the cupola should be rigorous to ensure the elimination of this source of trouble as far as is practicable.

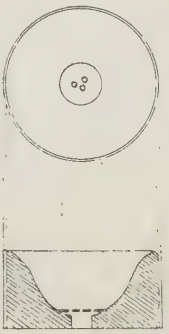


FIG. 17.—SUGGESTED METHOD FOR ENSURING CLEAN IRON IN CASTINGS.

Metal Faults

Compared with defects which may be attributed to moulding practice, the number of defects directly attributable to metal are relatively few. Nevertheless, by virtue of the complex nature of the material which the iron-founder has to handle, the troubles associated with his metal make up in quality the bugbears which it lacks in quantity, and the mastering of these is by no means an easy matter.

Cold shuts are one of the obvious metal faults, and in properly-controlled work should be of very infrequent occurrence. If metal of proper temperature be supplied to the moulder and due consideration be given to the sizes of gates

and their position to ensure the easiest and least tortuous filling of the mould no trouble on this account should arise. Damp sand, and cores improperly vented so that the metal does not lie quietly, also produce cold shuts, but in the majority of cases the defect arises from attempting to cast too many moulds from the one ladle of metal rather than return some metal or pour it on the floor, with the result that metal which has cooled below its useful lively state is used.

Gas-holes are often confused with blow-holes, but should be recognised as an entirely different trouble. These are usually brought to light when a top surface is machined, and in every

FIG. 18.—SHOWING CONVERSION OF A SHANK INTO A TEAPOT LADLE.

case are caused by pouring with metal which is too "stiff." It is now fairly well recognised that iron oxide is produced in cupola-melted iron. This oxide reacts with the carbon in the iron to give carbon monoxide, and the now gassy and more viscous metal rapidly loses its "life." On pouring, the gases in the metal and entrapped mould gases may rise to the surface or top of the mould but become trapped there under the rapidly-formed skin of the casting, giving rise to gas-holes which are only revealed under the surface when machining takes place. Had the metal been sufficiently hot, such gases would have risen to the top and escaped through the mould before freezing commenced and a solid

crust been formed. Hematite and so-called semi-steel mixtures are very prone to give this trouble if not cast hot, and in green-sand work the use of sand which is on the damp side aggravates it also.

Drawn, spongy or porous castings are nearly always due to solidification troubles. A drawn

FIG. 19.—EXPANSION SHOWN ON RISER.

hole as usually visualised is really an enlarged porous spot and is due to solidification taking place at different times in different parts of the casting. Porosity in general is a result of improper gating or feeding, and is aggravated by dull metal. If the metal is dull and the runner set before the casting has had time to feed,

not only will a shrinkage hole appear, but general porosity is highly probable. The early closing of the runner and consequent formation of a void below, by virtue of the shrinkage, results in the removal of the ferrostatic pressure at that point, and the iron just below will relieve itself of surplus gas held in solution. Moldenke has explained this very nicely when he likens the conditions to a bottle of soda-water which, upon removing the stopper, exhibits a

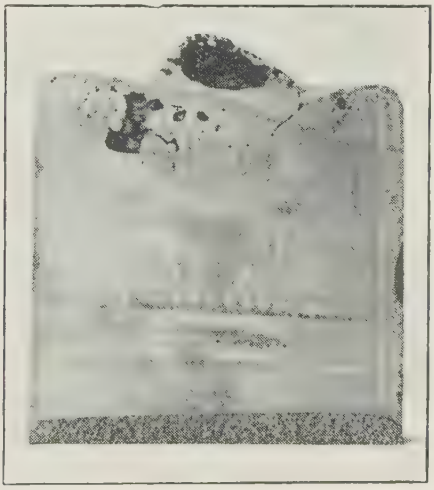


FIG. 20.—SECTION THROUGH FIG. 19.

series of bubbles at the top due to surplus gas being evolved through released pressure whilst the lower portion of the liquid retains its gas and quiescence. The bubbles in the iron may be too small to be seen, but they are there nevertheless and give rise to porosity.

Smalley has recorded his observation* to the effect that "Cupola-melted grey cast iron of normal chemical composition does not shrink on solidification if poured with a sufficient degree

* "Proc. I.B.F." Vol. XVI, p. 437.

of superheat and if cooled faster than a certain critical rate."

It has also been established that the more rapid the cooling, the less the liquid shrinkage of grey cast iron, and within certain limits of cooling hard iron and soft iron exhibit little or no volume change on solidification provided both are grey. This implies that there exists for each class of grey iron a minimum rate of cooling above which the metal will not shrink on solidification when poured at a suitable temperature, and a soft grey iron cooled more slowly than this

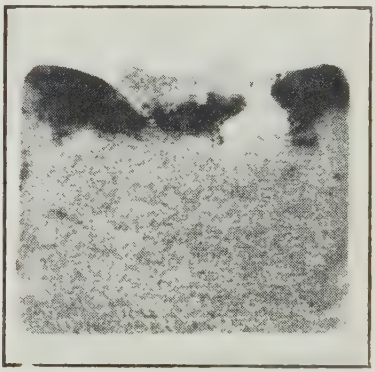


FIG. 21.—SULPHUR PRINT THROUGH FIG. 19.

minimum rate will shrink just as readily as a harder iron.

It is not possible, however, in practice to maintain the critical conditions necessary to ensure solidification without shrinkage, as above outlined, and it becomes necessary to adopt such measures as will counteract the effect of the divergencies from the ideal conditions. It is unnecessary to detail the methods used for this purpose; suffice to say that attention to position and size of runners and risers, hand feeding, etc., and the use of denseners at heavy sections

are usually sufficient to overcome the trouble, in conjunction with metal suited to the work on hand. In extreme cases it has been found that the addition of nickel in small amounts has proved successful in overcoming shrinkage where other methods failed.

While dealing with shrinkage, an interesting

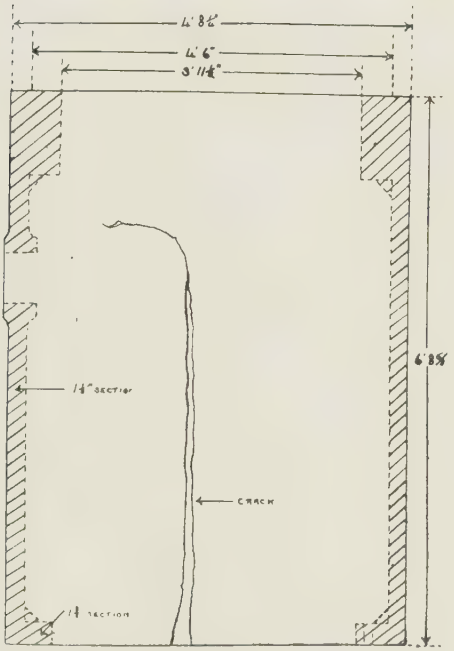


FIG. 22.—SECTION THROUGH CYLINDER CASTING WHICH CRACKED DURING STRIPPING.

feature observed recently is worth recording. In the case of oxidised metal, the occluded gases and dissolved oxide of iron tending to make them, may be sufficient not only to prevent shrinkage on the part of the iron, but actually to cause it to expand. In this way has arisen the peculiar feature observed on a riser, and

TABLE II.

Shrinkage Tests on Scrap from Cracked Stand-post, Remelted in Crucible. Dry-Sand Moulds using 1 in. sq. Bars.

Chemical analyses.						Casting temperature.	Linear shrinkage per ft.	Remarks,.
T.C.	C.C.	Si.	S.	P.	Mn.	In deg.C.	In in.	
3.99	0.91	0.84	0.026	0.18	1.18	1,200	0.120	Scrap without additions.
3.48	0.90	1.54	0.070	0.16	1.13	1,140	0.082	Scrap with ferro-silicon added.
3.59	0.73	1.85	0.039	0.16	1.20	1,200	0.1185	" " " "

Shrinkage Tests on Cupola Melted Grey Cast Iron. Dry-Sand Moulds using 1 in. sq. Bars.

Chemical analyses.						Casting temperature.	Linear shrinkage per ft.	Remarks.
T.C.	C.C.	Si.	S.	P.	Mn.	In deg.C.	In in.	
3.39	0.42	2.48	0.124	0.35	0.98	1,200	0.088	No. 1 Cupola Iron.
3.55	0.53	2.39	0.103	0.29	1.10	1,200	0.126	No. 1 Cupola Iron.
3.63	0.72	1.97	0.113	0.29	0.96	1,200	0.122	No. 2 Cupola Iron.
3.36	0.90	1.57	0.039	0.23	1.80	1,200	0.1185	No. 3 Cupola Iron.
3.47	0.88	1.36	0.088	0.18	1.25	1,200	0.122	No. 3 Cupola Iron.

Shrinkage Values Found by Various Observers. 1 *in. sq. Bars.*

Chemical analyses.						Casting temperatures	Linear shrinkage per ft.	Authority.
T.C.	C.C.	Si.	S.	P.	Mn.	In deg.C.	In in.	
3.45	0.35	2.75	0.09	1.45	0.95	1,350	0.152	I.B.F. Cast Iron Sub-Committee.
3.60	0.45	2.15	0.08	0.65	0.75	1,350	0.140	,, ,,
3.30	0.62	2.03	0.11	0.79	0.72	1,400	0.152	,, ,,
3.30	0.62	2.03	0.11	0.79	0.72	1,350	0.154	,, ,,
3.30	0.62	2.03	0.11	0.79	0.72	1,325	0.154	,, ,,
—	—	2.23	—	—	—	—	0.124	Keep.
—	—	2.01	—	—	—	—	0.143	,,
—	—	1.21	—	—	—	—	0.150	,,
—	—	1.17	—	—	—	—	0.145	,,
3.52	0.79	1.41	0.07	0.96	0.43	—	0.133	Turner.

illustrated in Figs. 19 to 21. It will be seen from the shape of the riser that a slight shrinkage has taken place initially, but this has been rapidly overcome by an expansion which actually forced metal out of the riser. The sulphur print shown in Fig. 21 affords indication that the casting temperature has been sufficiently high, and

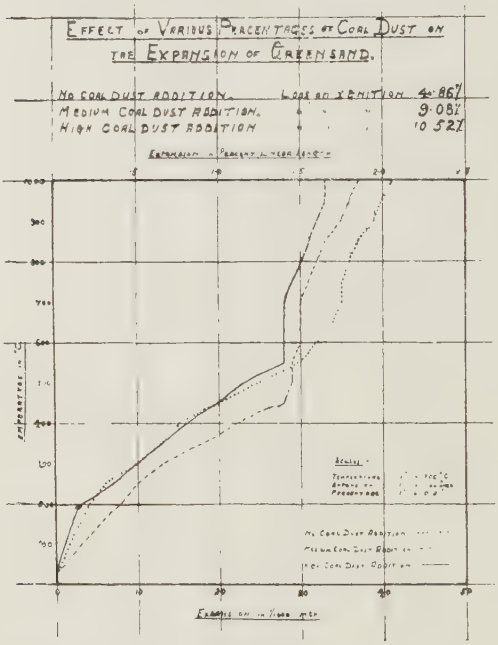


FIG. 23.—EFFECT OF COAL-DUST ADDITIONS ON EXPANSION OF ORDINARY GREEN SAND.

the only assumption that can be made is as explained above, to the effect that the liberated gases have expanded in the metal and forced the still molten residue up the riser.

Total Shrinkage

Contraction or *total shrinkage* is another subject upon which much has been written

during the past few years, but in the majority of cases the results are so obscured by masses of data that the average foundryman is largely in the dark as to what conclusions may be drawn from them. In this connection, it will be interesting, and probably profitable, to examine an actual case of fracture through contraction for which no allowance was made, but it should be realised that the remarks apply in this case to castings of a heavy nature. Fig. 22 gives a sectional view of the casting in question, which cracked whilst being stripped from the mould some 19 hrs. after casting. The job was made

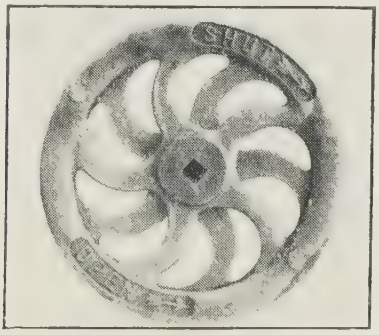


Fig. 24.—Curious Defect due to Faulty Box-Part Registration.

in loam with a loam core, and it was not considered necessary to effect any slackening. The fracture was typical of grey cast iron with a slightly open grain, and the metal on analysis showed:—Total carbon, 3.98 per cent.; graphitic carbon, 3.00; combined carbon, 0.98; silicon, 1.43; manganese, 1.17; sulphur, 0.06; and phosphorus, 0.15 per cent.

The Brinell-hardness number of the $1\frac{1}{8}$-in. section was 179. It was contended that the fracture was entirely due to an excessively-high contraction in the metal, but such is not to be expected from an iron of the quality shown.

Shrinkage test-bars 1 in. sq. were cast in dry-sand moulds to duplicate practical conditions as far as possible using the scrap from the broken-up casting remelted in a crucible. At the same time, comparative tests of the various grades of iron in use in the works were cast and the shrinkage values obtained are set out in Table II along with values obtained by various other observers. It will be seen that in the case under review the linear shrinkage is below the accepted figure of $\frac{1}{8}$ in. per ft. and much below the values recorded for similar irons by other observers. A survey of the Tables shows further that within the limits of composition specified for general engineering castings, the linear shrinkage is not effected by composition to any appreciable extent provided the silicon does not rise above 2.5 per cent. and the fracture of the iron remains grey. This shows that the metallurgist has little control over the metal contraction within these limits.

The only other factors associated with the metal and having a bearing upon the defect are the strength and stretching capacity of iron at elevated temperatures. It is not generally appreciated that down to 500 deg. Fah. (260 deg. C.) all grey cast iron is capable of stretching. Smalley has also investigated these factors* and shown that the higher the silicon the greater is the extensibility hot, or, in other words, the softer the iron the more readily will any casting accommodate itself to stresses caused by the effect of constriction and restricting cores, etc. In Table III the strength figures for grey cast iron at elevated temperatures are given, and it will be further noticed that the softer high-silicon and high-phosphorus irons are much weaker at high temperatures than irons of lower silicon and phosphorus contents.

These results throw considerable light on the question of cracked castings and indicate the position which the foundryman or metallurgist must take up when preparing his charge for any particular type of casting. All grey irons are

* Proc. I.B.F., Vol. XV, p. 702.

TABLE III.— *Tensile Strength of Grey Cast Iron at Elevated Temperatures.*

Chemical Analyses.						Tensile strength in tons per sq. in. at deg. F.					
T.C.	C.C.	Si.	S.	P.	Mn.	1,400	1,200	1,000	800	500	Room temperature.
3.65	0.15	2.92	0.062	1.26	0.49	1.75	4.96	10.00	11.00	9.90	12.00
3.08	0.60	2.00	0.089	0.096	0.57	3.80	6.90	13.50	18.20	16.30	17.80
3.31	0.60	.50	0.112	0.49	0.74	4.00	7.00	14.00	17.00	16.20	17.75

extensible when hot to some extent, and therefore capable of accommodating themselves to stresses set up by constricting cores, etc., but irons of sufficiently-high stretching capacity are of such a composition as to preclude their use for large castings on the grounds that satisfactory castings could not be made from them. It is therefore obvious that cracking of large castings of the composition demanded by modern practice can only be avoided by (1) releasing or

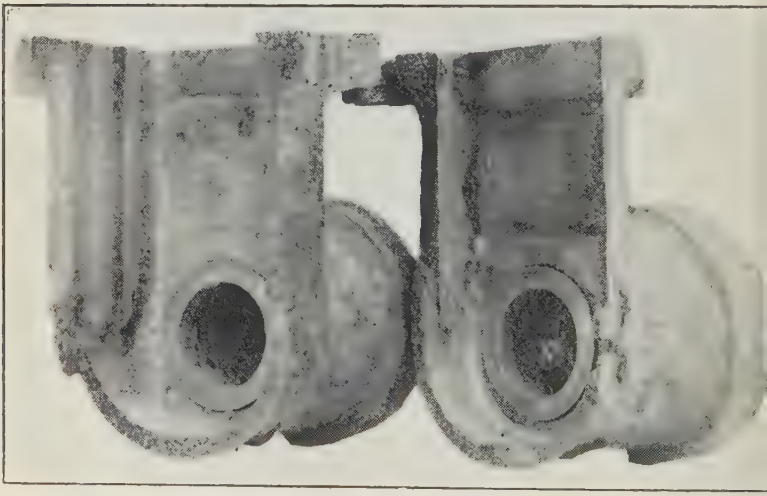


FIG. 25.—DEFECT DUE TO INTERRUPTED POURING.

removing restricting cores, etc., while the casting is at a dull red heat (650 deg. C.); (2) by retarding the rate of cooling during the "blue-brittle" range of temperature (approximately 500 to 600 deg. C.) to a rate of approximately 10 deg. C. per hr., and (3) by accelerating the cooling of heavier sections or retarding the cooling of lighter sections in order to obtain uniform cooling as a whole.

It may also be of interest to point out that an investigation of the expansion of moulding

materials, sand and loam, etc., has shown that these expand by amounts up to and over 0.2 in. per ft. on heating to 1,000 deg. C., a figure which is in excess of the shrinkage values found for grey iron, and hence in a mould there exists two forces directly opposing one another and tending to pull the casting apart. Experiments appear to indicate that sand mixtures may be obtained in which the expansion of refractory is reduced to a minimum as is illustrated in Fig. 23, which shows the effect of coal-dust additions to ordinary green sand in so far as refractory expansion is concerned; but in view of the incompleteness of existing knowledge of the subject at

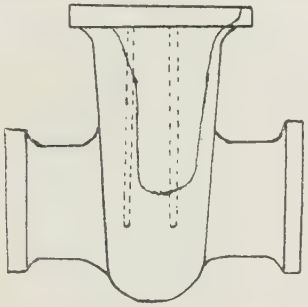


FIG. 26.—NATURE OF DEFECT SHOWN IN FIG. 25.

the present stage, and also the lack of knowledge on the strength of sand or loam in mould or core formation at elevated temperatures, the safer plan, if wasters are to be avoided, is to remove all restricting cores, etc., rather than rely on such restrictions collapsing under the pressure of the shrinking casting.

Bad Work

The term "bad work" has been used for lack of a better designation, and is intended to cover such types of defect as may easily be avoided by reasonable care on the part of the moulder. Under this category may be considered

the closing of moulds wrongly, omission of small cores, short pours, interrupted pours and breakages due to the opening of moulds or removing of runners and risers before the casting is properly set. Fig. 24 is an illustration of one of these types, and presents an amusing appearance. It is confessed that, when first shown the hand-wheel, the author was struck by its appearance and imagined it to be a new design. Closer examination, however, revealed the casting as a defective one, arising from incorrect registering of the cope and drag.

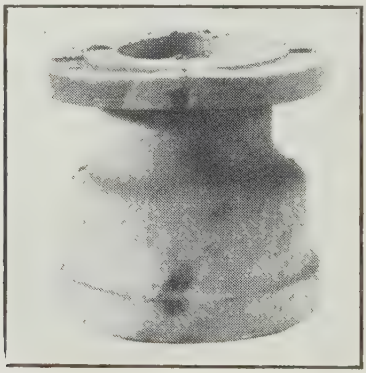


Fig. 27.—Defect due to Breaking off a Runner too Early.

Fig. 25 shows a valve which burst under test, and an inspection of the casting reveals a defect resembling a cold shut extending from the top flange down the corner of the valve body to a point in line with the waterway and on the side of the valve cast upwards. On breaking the valve body further, it was discovered that the corresponding side of the casting exhibited the same cold shut appearance, extending from the square flange to the ring seat, as shown in Fig. 26. It was evident, then, that the defect was not a cold shut. The valve being cast from

the top, failure has arisen through an interrupted pour, either a run-out or a shortage of metal followed by the addition of more metal, which has failed to weld solidly with the metal already in the mould and which was probably set. The remedy in such cases is, of course, perfectly obvious.

As a final example of how defects arise, Fig. 27 illustrates a casting which has been sacrificed to time. Obviously, the moulder or his boy has been too anxious to get the runner and riser broken, with the result that the flange of the casting has been cracked and twisted out of shape while still in a plastic state. Defects of

TABLE IV.—*Analyses of Defective Castings.*

Classification.	Percentage on total castings.	
	1932–33.	1933–34.
Mould and core faults ..	0.801	0.684
Sided	0.154	0.119
Blow-holes	0.269	0.251
Sand holes	0.770	0.365
Slag holes	0.224	0.315
Metal faults	0.207	0.129
Bad work	0.323	0.329

this type are happily not so frequent, but should never occur.

The successful elimination of defective castings is not a matter which either foundry artisan or metallurgist alone can accomplish, but requires rather the close co-operation of both. In the foundry, rigid supervision is essential in these days of mass production to eliminate as far as possible the elements of uncertainty introduced by man's human failings, and on the part of the technical staff as rigorous control is required to ensure uniformity in the raw materials supplied to the practical man. Where such is the practice, successful results can be looked for and, indeed, accrue, as shown in Table IV, where the percentage defectives arranged in

accordance with the classification used throughout this Paper and calculated on the total castings produced in the light-castings foundry of the author's employ, are recorded for the years 1932-33. It will be seen that there is a decided reduction in all but two cases, which are capable of explanation. The increase in slag holes is due to the fact that hotter metal is in use now than ever before, and for a time it was not realised that this was giving rise to increased slag through the fusion of the refractory used for lining the ladles. The very slight increase in defects under bad work is undoubtedly due to to increased production of green-sand castings, formerly made in dry sand. The results on the whole amply justify the control exercised.

In conclusion, the author wishes to convey his indebtedness to Mr. Gardner, works manager, and the directors of Messrs. Glenfield & Kennedy, Limited, for permission to use the data accumulated as a result of the numerous investigations carried out; also to Mr. Hudson, chief chemist, for his collaboration in carrying through the work and his assistance in compiling the present Paper.

Birmingham Branch.

CUPOLA PRACTICE WITH A VIEW TO CLOSER CARBON CONTROL

By W. H. Bamford (Member).

In these days a Paper upon carbon control is by no means rare; in fact, judging by the number of articles published, too, on the effects of carbon in cast iron, it would seem that it is a fairly common subject, but at the same time, it also shows that it is of great interest to the majority of foundrymen.

There is nothing very startling in the control of the elements in the cupola when using straight pig and scrap mixtures, as the difference of these in the pig-iron and scrap is comparatively slight, and one can depend upon the usual 10 per cent. loss in silicon and the carbon tending to move towards its eutectic composition, unless something is radically wrong with one's practice.

When melting steel mixtures with a view to casting the product directly into castings, the difficulties are greatly increased, as the materials necessary, that is, the pig-iron and steel, are widely different in character, with a consequent difference in their reactions in the cupola; the melting points and specific gravity are widely dissimilar, which make much greater precautions necessary than with plain pig and scrap charges.

The greatly superior product obtained with steel, however, more than justifies its inclusion in the charge, while the greater precautions needed are made worth while, if only for a saving in cost of material, steel scrap being much cheaper than pig.

Although semi-steel has been in general use for a considerable time, so far as can be ascertained, no particulars have been published relating to

its continuous melting and direct casting over a period of 8½ to 9 hrs. a day, with the object of maintaining a constant chemical composition of the melt essential for repetition castings required for strength and freedom from all metal troubles.

It is the object here, therefore, to give a few details of experiences with this type of metal, as it has been found that, by suitably balancing the charges, it is possible to obtain an iron of almost any carbon content desired, keeping it to within as close limits as those obtained from electric furnaces, and far more cheaply. Along this path of precision in control of carbon lies the manufacture of alloy cast iron in the cupola also. To return to steel mixtures, while the saving in cost of materials has been considerable, there has also been a saving as a result of less scrap due to metal troubles, for which the introduction of steel has been largely responsible, mainly by lowering the total carbon.

With steel mixtures, difficulties arise in the control of the chemical composition, the total carbon offering the greatest, with the silicon becoming a poor second, but, with care and close supervision, it is possible to bring them both within very reasonable limits throughout a cast of 8 or 9 hrs., from the first ladle of iron tapped, until the last metal is drained from the well.

Details of the Melting Plant

Two cupolas are used for melting the cylinder iron, each with a shell of 54 in. lined to 40-in. dia. One is in use while the other is in course of preparation. They are of the soft-blast type, with a melting zone to tuyere ratio of 5 to 1. Blast is provided by a No. 3 Rootes blower, delivered at a pressure of 16-in. water gauge in the wind belt, and which may be by-passed to either cupola as needed. Metal is tapped into 6-cwt. ladles carried on overhead monorails to two mould conveyors, one bearing monobloc moulds and the other cylinder-head moulds.

It should be noted here that both monoblocs and heads are cast with similar iron, in green sand, no special distinction being shown to either;

so that an iron conforming to both classes of castings is imperative. These conveyors are situated close to the melting section, so that little heat is lost during the transit of the metal to the moulds. This is important when dealing with a quick-setting iron, as any delay would give inconvenience from dull iron. An endeavour is made to cast all moulds as they proceed past the pouring station, or, in other words, synchronisation must be maintained between moulding and melting sections to give constant melting conditions in the cupola with the minimum of inconvenience from surplus or insufficient metal.

Cupola Preparation

Referring to the melting section, the cupolas are lit when preparation is finished, and the fire kept burning slowly throughout the night by night workers. If the ingress of air is strictly limited, combustion is slow and little coke is wasted. This serves the dual purpose of preventing spalling of the lining and aids in starting with a thoroughly incandescent bed, so necessary in order to obtain hot iron at the commencement of the blow. The blast is put on at approximately 8 a.m., and metal is usually ready for the first moulds to reach the pouring station about half an hour afterwards.

It is worthy of note that by having picked coke for the bed, and taking pains to obtain a highly-incandescent bed prior to charging, with the extra advantage of preheated ladles, it is possible to tap out at the commencement, metal sufficiently hot to cast cylinders and heads without having any of the inconvenience of dull iron. Indeed, this has become a general practice, due mainly to the willing co-operation of the staff attached to the cupolas, who, very humanly, dislike extra work in pigging cold iron.

The main feature of both the cupolas is in the wells. These are lined to hold their utmost capacity of iron, which is 30 cwts., when full to the slag hole. The wells, therefore, act as mixers in a modest way. Metal is tapped only when it

is about to appear at the slag hole, which is kept permanently open during the day; this rule is never broken, unless unforeseen circumstances arise, and this partly makes it possible to control the silicon and phosphorus fairly closely.

Charging Details

A further and equally great precaution to ensure good mixing lies in the weight and position-

Fig. 1.—Fractures of Transverse Bars, having High (3.60), Medium (3.26), and Low (2.97 per cent.) Carbon, with Constant Silicon (2.10 per cent.).

ing in the furnace, of the charges, which are composed of 4 per cent. silicon pig, own return scrap, and steel in suitable proportions to give a silicon content of between 2.1 and 2.3 per cent. and phosphorus not exceeding 0.25 per cent. The steel scrap added, which is of varied sections, never less than $\frac{1}{4}$ in., is in the proportion of 15 per cent. This percentage has been found to be the most economical for the production of

the carbon content most suitable for cylinder castings, and it is safe to say that it has not been altered to any appreciable extent for eighteen months. The charges are weighed in thousand pounds on dial-reading scales, but the materials are halved when placed in the cupola. This makes the charge only 500 lbs., which is small in comparison with a normal one for a furnace of this capacity, but the object will be appreciated when it is realised that there are always between five and six charges in the well.

Cupola practice in the past has recommended that the charges should be proportioned according to the weight of coke occupying a known depth in the shaft. While this may be usual, no

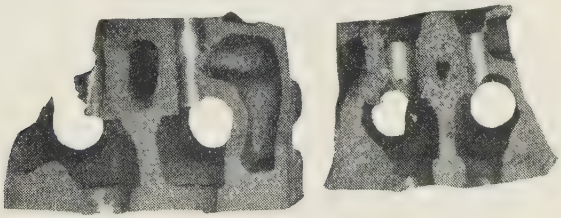


Fig. 2.—Valve Guide Holes having High (3.57) and Normal (3.60) Carbon, with Silicon at 2.10 per cent.

difficulty has arisen as a result of reducing the weight of the charge, and similarly the coke, which is insufficient entirely to separate one charge from another.

The steel scrap is scattered over the coke, the pig placed around the edge, and the lighter scrap distributed evenly over the whole. Melting is thus very regular, and at the same time the metal is quite hot, probably in the region of 1,400 deg. C. This is most important when dealing with a quick-setting iron possessing a high freezing range.

From a description of the cupola practice and the precautions taken to keep the silicon and phosphorus within limits, it is thought advisable

TABLE I.—*Control of Cylinder Iron Composition.*

No.	C.C.	T.C.	Mn.	S.	P.	Si.	Br.	Chill in in.	Shrink in in. per ft.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			
1	0.60	3.55	0.96	0.105	0.30	2.24	228	$\frac{2}{32}$	0.168
2	0.53	—	—	—	—	2.27	241	$\frac{3}{32}$	0.147
3	0.47	3.22	0.86	0.107	0.31	2.18	241	$\frac{3}{32}$	0.178
4	0.51	—	—	—	—	2.22	228	$\frac{2}{32}$	0.155
Lunch hr.									
5	0.52	—	—	—	—	2.18	228	$\frac{1}{32}$	0.160
6	0.50	3.36	0.84	—	0.29	2.04	241	—	—
7	0.53	—	—	—	—	2.09	241	$\frac{2}{32}$	0.160
8	0.53	3.36	0.80	0.096	0.30	2.10	241	$\frac{1}{32}$	0.159

High bed at commencement of melting results in high carbon, producing low chill.

TABLE II.—*Control of the Properties of Cylinder Iron.*

No.	C.C.	T.C.	Mn.	S.	P.	Si.	Br.	Chill in in.	Shrink in in. per ft.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			
1	0.64	3.05	0.79	0.096	0.23	2.09	241	$\frac{3}{16}$–$\frac{3}{32}$	0.205
2	0.60	—	—	—	—	2.05	241	$\frac{3}{32}$–$\frac{1}{16}$	0.160
3	0.54	3.46	—	—	—	2.04	228	$\frac{1}{16}$–$\frac{3}{32}$	0.159
4	0.60	—	—	—	—	2.02	241	$\frac{3}{32}$–$\frac{1}{16}$	0.165
5	0.53	3.22	—	—	—	2.00	241	$\frac{3}{32}$–$\frac{3}{32}$	0.199
6	0.54	—	—	—	—	2.06	241	$\frac{3}{32}$–$\frac{3}{32}$	0.185
Lunch hr.									
7	0.57	3.19	0.94	0.095	0.21	2.07	255	$\frac{3}{32}$–$\frac{3}{32}$	0.197
8	0.56	—	—	—	—	2.04	248	$\frac{3}{32}$–$\frac{1}{16}$	0.169
9	0.53	—	—	—	—	2.03	241	$\frac{3}{32}$–$\frac{1}{16}$	0.157
10	0.56	—	—	—	—	2.15	241	$\frac{3}{32}$–$\frac{3}{32}$	0.162
11	0.51	3.30	1.04	0.093	0.21	2.26	228	$\frac{3}{32}$–$\frac{3}{32}$	0.159

Low bed at commencement produces low carbon with increased chill and shrinkage. The low carbon in the middle of the day, Nos. 5 to 7 also produced high chill and shrinkage.

to proceed next to the most important element present in cast iron, which is carbon. It has been found that for strong castings of fairly close grain, with easy machining qualities, the most satisfactory carbon content lies between 3.1 and 3.3 per cent. Before going into details, however, concerning the control of this element, it is probably as well to discuss the troubles which arise when it gets out of control, for it is more from mistakes and their rectification that information is gained, than from anything else.

Melting Troubles

Broadly speaking, metal troubles experienced with monoblocs and heads can be assigned to two main causes, which are:—(1) Open metal and porosity; and (2) hard or chilled iron. They are directly opposed to each other, and are the result of exactly opposite conditions. For example, if one of these is experienced in a casting, the other will certainly not be there; this remark applies solely to the type of iron and castings under discussion; no attempt is made at generalising. To counteract the first, that is, open metal, numerous suggestions have been advocated, but all with the same intention of producing castings of a quick-setting iron. One of these recently was to decrease the phosphorus to as low a limit as convenient in order to prevent segregation of phosphide eutectic, which, freezing in the region of 800 deg. C., naturally extended the setting time of the iron considerably, although against this it must be argued that perfectly good cylinders have been made with high phosphorus iron, so it is assumed that phosphorus in itself is not a direct cause of porosity.

If design of the casting does not enter into the problem of open metal, then the chief causes are as follow, in order of importance:—(1) High carbon; (2) high silicon; and (3) high casting temperature. Each of these factors is known to be capable of exerting an influence over the growth, and, therefore, the ultimate size of the graphite crystals, although probably in different ways.

High silicon opposes retention of carbon in solution; it is reasonable, too, to expect more graphite to be present in a high-carbon iron than in a low one; high casting temperature would certainly aid graphitisation by prolonging the time of cooling during the critical stages. While these are all contributory causes of open metal and porosity, it will be seen that they are directly associated with the precipitation of carbon.

Hard or chilled castings, on the other hand, are the result of opposite conditions, as stated previously, which are:—(1) Low carbon; (2) low silicon; and (3) low casting temperature. Here, again, it is the carbon that is the predominating factor, upon whose inadequacy the cause of the defect must lie, because necessary precautions have been taken to prevent bad mixing, while low casting temperature is due to the human element. Ruling out, therefore, the possibility of these two as unlikely causes of hard castings, it is evident that excessively low carbon is also a thing to be avoided as completely as is high carbon.

The pursuit of a quick-setting iron which does not readily chill lies, therefore, in a correct balance of the carbon to suit the casting, remembering that it is the most fluidising element present in iron. This will be more greatly appreciated after a study of the iron-carbon diagram, which shows that even slight differences in the amount of carbon present will alter considerably the temperature at which the iron commences to freeze.

Influence of Carbon

The influence of carbon is shown by Figs. 1 to 5, which illustrate defective castings, the chemical compositions of which are normal, except for this one element. Figs. 4 and 5 show castings possessing extremely high-carbon contents, which defect has been augmented by high casting temperature. They should not only open grain structures, but also liquid shrinkage, cavities or "draws." These cavities are caused by excessively fluid iron setting over a longer period

TABLE III.— *Control of the Properties of Cylinder Iron.*

No.	C.C.	T.C.	Mn.	S.	P.	Si.	Br.	Chill in in.	Shrink in in. per ft.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			
1	0.58	3.33	0.98	0.105	0.22	2.07	228	$\frac{1}{2}$	0.170
2	0.52	3.55	—	—	—	2.05	228	$\frac{1}{2}$	0.160
3	0.50	3.60	—	—	—	2.02	241	$\frac{1}{2}$	0.160
4	0.51	—	—	—	—	2.16	269	$\frac{1}{2}$	0.160
5	0.54	—	—	—	—	2.03	241	$\frac{1}{2}$	0.164
Lunch hr.									
6	0.56	—	1.00	0.110	0.22	2.09	228	$\frac{1}{2}$	0.163
7	0.50	3.38	—	—	—	2.23	241	$\frac{1}{2}$	0.156
8	0.52	—	—	—	—	2.18	228	$\frac{1}{2}$	0.160
9	0.50	3.46	—	—	—	2.14	228	$\frac{1}{2}$	0.160
10	0.54	3.30	0.96	0.107	0.19	2.07	228	$\frac{1}{2}$	0.142

Fusion charges too heavy. Note gradual increase of carbon and reduction in chill. This was remedied and remaining figures are normal.

TABLE IV.— *Control of the Properties of Cylinder Iron.*

No.	C.C.	T.C.	Mn.	S.	P.	Si.	Br.	Chill in in.	Shrink in in. per ft.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			
1	0.56	3.44	0.84	0.099	0.30	2.24	241	$\frac{1}{16}$	0.169
2	0.53	—	—	—	—	2.27	241	$\frac{3}{32}$	0.160
3	0.52	—	—	—	—	2.30	241	$\frac{1}{8}$	0.163
4	0.52	—	—	—	—	2.26	241	$\frac{5}{32}$	0.161
5	0.50	3.11	—	—	—	2.28	241	$\frac{3}{16}$	0.188
Lunch hr.									
6	0.52	3.41	0.86	0.115	0.32	2.21	228	$\frac{1}{32}$	0.163
7	0.50	—	—	—	—	2.30	241	$\frac{1}{16}$	0.157
8	0.52	—	—	—	—	2.32	235	$\frac{3}{32}$	0.164
9	0.50	3.14	—	—	—	2.28	241	$\frac{1}{8}$	0.188
10	0.52	—	0.86	0.115	—	2.22	241	$\frac{5}{32}$	0.159

Fusion charges too light. This was balanced after the lunch hour by the extra coke added for this purpose, but the height of the bed gradually dropped.

than usual, which would be the case with a high-carbon iron, on account of its lower freezing temperature. If examined closely, they reveal themselves as composed of a network of dendrites of low-carbon iron, from which has receded the iron richer in carbon to feed other sections. This, again, is proved by the iron-carbon diagram in the liquidus and solidus curves, which show that iron, low in carbon, is the first to freeze, and, as crystallisation proceeds, the remaining liquid becomes richer in carbon, until freezing is complete.

When the carbon is known to be too high, the

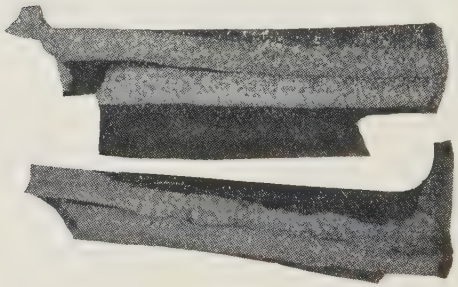


FIG. 3.—CYLINDER BORES, LONGITUDINAL SECTION, WITH NORMAL AND COARSE GRAIN (C 3.58 AND 3.26).

obvious precaution *id est* to reduce the ill-effects resulting is to depress the casting temperature, in order to shorten the setting time and aid chilling, but even here, increased precipitation and growth of graphite is inevitable, giving a more or less coarse grain structure.

Even when working with a low-carbon iron, this precaution is sometimes necessary with certain types of castings; for example, the smaller monoblocs the casting temperature of which is always strictly limited to produce a fine grain, owing to its small size and proportionately thicker sections being more conducive to open metal. All the illustrations demonstrate

that control of the carbon is essential for success in minimising scrap, especially to a foundry engaged in repetition work, where no stone should be left unturned in maintaining consistency of product.

Factors Influencing Carbon Control

It is possible to keep the silicon and phosphorus constant, as previously stated, by reducing the size of the charge, increasing the capacity of the well, and taking care to tap out only

Fig. 4.—Cylinder Bores, showing Open Grain and Shrinkage (C, 3.61; Si, 2.15).

when the well is full, but, unfortunately, the total carbon is not controlled so easily. The carbon content of the melt is dependent entirely upon other factors, of which the main ones are:—(1) Height of the coke bed; (2) size of the coke in the bed; and (3) quality of the coke used. As most of the fans or blowers used on cupolas are installed to suit individual furnaces, the quantity of air delivered need not be considered here, except when the furnace is being blown down, when, of course, it is necessary slowly to reduce the blast to coincide with the gradual

TABLE V.—*Control of the Properties of Cylinder Iron.*

No.	C.C.	T.C.	Mn.	S.	P.	Si.	Br.	Chill in in.	Shrink in in. per ft.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			
1	0.52	3.30	0.96	0.097	0.26	2.10	228	1/32	0.160
2	0.52	—	—	—	—	2.22	228	2/32	0.163
3	0.48	—	—	—	—	2.18	235	2/32	0.157
4	0.46	—	—	—	—	2.12	228	2/32	0.159
5	0.50	3.14	1.06	0.097	—	2.24	241	3/32	0.184
Lunch hr.									
6	0.53	3.16	—	—	—	2.16	241	2/32	0.189
7	0.46	—	—	—	—	2.28	241	2/32	0.163
8	0.51	—	—	—	—	2.28	255	2/32	0.160
9	0.50	—	—	—	—	2.23	255	3/32	0.159
10	0.49	3.33	1.22	0.101	0.28	2.25	228	1/32	0.167

Low carbon at the lunch hour, probably due to collapse of ganister patching and insufficiently balanced by the extra coke.

TABLE VI.– *Control of the Properties of Cylinder Iron.*

No.	C.C.	T.C.	Mn.	S.	P.	Si.	Br.	Chill in in.	Shrink in in. per ft.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			
1	0.47	3.46	0.78	0.105	0.28	2.28	228	$\frac{16}{32}$	0.155
2	0.52	—	—	—	—	2.30	228	$\frac{15}{32}$	0.162
3	0.51	—	—	—	—	2.26	228	$\frac{19}{32}$	0.163
4	0.50	—	—	—	—	2.28	228	—	—
Lunch hr.									
5	0.51	3.44	0.86	0.124	0.30	2.18	228	$\frac{17}{32}$	0.160
6	0.44	—	—	—	—	2.28	228	$\frac{17}{32}$	0.160
7	0.46	—	—	—	—	2.28	228	$\frac{21}{32}$	0.158
8	0.51	3.14	0.88	0.116	0.30	2.20	255	$\frac{31}{32}$	0.197

Low carbon at end of day due to not regulating the blast to coincide with the lowering of resistance in shaft.

lowering of the resistance in the shaft. With some fans, even this becomes unnecessary, as they are designed to give a constant air weight irrespective of any variation of resistance in the cupola.

The quantity and quality of the coke used are the all-important factors which govern the absorption of carbon in melting, which in turn has a direct influence upon the hardness, fluidity, and consequently the soundness of the iron at any particular time of melting. The reason is that the greatest amount of pick-up occurs in the melting zone, which is the hottest part of the cupola; the pick-up elsewhere is negligible. This was proved by examination of samples taken from the cupola as follows:—(1) Samples of partly-melted steel recovered from the drop revealed only slight skin penetration, and (2) prolonged proximity of metal and coke in the well has no influence on the carbon absorption whatever. This has been confirmed on numerous occasions by Mr. W. B. Parkes, chemist at the Austin Motor Car Company, during the last three years, who has tested samples of iron which have remained in the well for nearly 2 hrs. The carbon contents were no higher than the usual figures.

The pick-up of carbon in the melting zone and not in the other part of the shaft or well is explained by the greater affinity of iron for carbon at elevated temperatures, such as those occurring in the melting zone, where the iron probably reaches a temperature in the region of 1,500 deg. C.

Carbon Pick-up in Well

Disregarding the pick-up in the well and the upper part of the shaft as negligible, places the bed in greater prominence as that portion of the furnace which controls the resulting carbon content of the iron, that is, if the bed be high; the reverse naturally obtains if the bed is low. Thus the rate of absorption increases or decreases according to the quantity of incandescent coke exposed to the liquid iron running through the

bed. A similar condition arises when an excessive quantity of small coke is charged, which when it reaches the bed affords ideal condition for increased pick-up. These facts prove that the control of the carbon lies fundamentally in the control of the bed, that is, in maintaining a height most suitable for the required carbon content, having regard also to keeping a good average size of coke in each charge neither excessively large nor yet too small. By keeping the height of the bed constant the carbon pick-up will also keep constant for as long a period as melting continues.

Assuming that a highly superheated iron is required for thin castings, it seems inevitable that in raising the bed necessary for the additional heat required, the carbon in the melt is increased out of all proportion to the limits stipulated for a close-grained casting free from porosity. How is it possible, therefore, it may be asked, to obtain a low-carbon iron with a high degree of superheat also? The answer lies, firstly, in the selection of the steel scrap and the quantity it is possible to include in the charge without seriously lowering the silicon content, and secondly, in the quality or grade of coke used.

Steel Scrap Selection

In reviewing the first part, that of selection and quantity of steel used, it has been found that thick-sectioned steel permits of less carbon absorption than does thin-sectioned steel, and where possible it could be used; but in circumstances where it is necessary to utilise the materials at hand, for example, mixed scrap, it is advisable to seek other means of keeping the carbon low. Again, an increase of steel to this end is not often economical, as it entails an increase of pig also to preserve the required silicon, thus reducing the percentage of return scrap in the charge accordingly.

Influence of Coke Reactivity

Ruling out any alteration in the percentage of steel used as impracticable, it is the quality of

TABLE VII.—*Control of the Properties of Cylinder Iron.*

No.	C.C.	T.C.	Mn.	S.	P.	Si.	Br.	Chill in in.	Shrink in in. per ft.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			
1	0.56	3.41	0.92	0.097	0.29	2.02	241	$\frac{17}{32}$	0.160
2	0.53	3.57	—	—	—	2.12	207	$\frac{9}{32}$	0.158
3	0.53	3.55	—	—	—	2.12	228	$\frac{9}{32}$	0.168
4	0.52	—	—	—	—	2.16	228	$\frac{14}{32}$	0.160
5	0.53	—	—	—	—	2.22	217	$\frac{13}{32}$	0.152
6	0.50	—	1.04	0.110	0.28	2.18	217	$\frac{11}{32}$	0.159
Lunch hr.									
7	0.55	—	—	—	—	2.02	228	$\frac{15}{32}$	0.160
8	0.49	3.61	—	—	—	2.17	207	$\frac{10}{32}$	0.160
9	0.50	—	—	—	—	2.08	228	$\frac{13}{32}$	0.158
10	0.56	—	—	—	—	2.06	241	$\frac{20}{32}$	0.155
11	0.50	3.43	1.02	0.099	0.28	2.06	228	$\frac{17}{32}$	0.155

High carbon persisting through day due to incorrect weight of fusion charge combined with large amount of small coke. This gave trouble due to open metal and porosity.

TABLE VIII.—*Control of the Properties of Cylinder Iron.*

No.	C.C.	T.C.	Mn.	S.	P.	Si.	Br.	Chill in in.	Shrink in in. per ft.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.			
1	0.59	3.11	1.26	0.090	0.22	2.30	—	$\frac{1}{8}$	0.166
2	0.53	3.11	—	—	—	2.32	—	$\frac{3}{16}$	0.160
3	0.55	—	—	—	—	2.24	—	$\frac{3}{16}$	0.163
4	0.56	—	—	—	—	2.26	—	$\frac{3}{16}$	0.158
5	0.50	3.22	—	—	—	2.28	—	$\frac{3}{16}$	0.164
Lunch hr.									
6	0.51	—	1.20	0.118	0.22	2.21	—	$\frac{3}{16}$	0.163
7	0.55	—	—	—	—	2.32	—	$\frac{3}{16}$	0.165
8	0.53	—	—	—	—	2.32	—	$\frac{3}{16}$	0.166
9	0.52	—	—	—	—	2.30	—	$\frac{3}{16}$	0.154
10	0.50	3.16	1.16	0.123	0.22	2.28	—	$\frac{3}{16}$	0.162

Normal day's results of a more recent day's cast. Note the lower carbon balanced by increased silicon.

coke which must be reviewed in order to obtain one which, when extra is added to the charge for additional superheat, does not give appreciable carbon increase. In other words, the degree of absorption depends partly upon one other factor, which is the reactivity of the coke employed. The reactivity varies according to its density, the heavy dense types having a low reactivity, while the lighter, more open grades, such as gas coke, to quote an extreme, have a high reactivity.

The heavier types carburise less readily than do the lighter grades, and by the use of the former it is possible to keep the carbon pick-up to low figures, even when using increased coke to obtain very hot iron, such as is necessary for cylinders.

As an example, given similar irons and identical melting conditions, but using two different qualities of coke, it is possible that the carbon in the melts could vary as much as 0.4 per cent. one with the other. This is the most important feature of the whole, as upon the wise choice of a suitable grade of coke, balanced with the metal charged, a definite amount of carbon can be obtained in the melt for as long a period as desired.

Fig. 6 shows a comparison between two types of cupola coke; one is dense and heavy and admirably suited for the production of high temperature, low-carbon iron, the other is a less dense but equally good-quality coke, which when attempts have been made at increasing the height of the bed in order to obtain hotter iron, has resulted in an iron much higher in carbon than required.

Prior to using the dense coke, efforts were made to reduce the higher reactivity of the more open-grained coke, especially at the commencement of the day. At the start it is always necessary to have the bed much higher than the normal working height, for obvious reasons, so that unless precautions are taken to counteract the influence of the high bed the carbon pick-up would be great. It was the general practice, therefore, to build up the bed to the required

height with large coke, which had been dipped in lime wash, the covering of lime lowering the reactivity appreciably. The first few charges of metal and coke were also limed. At the end of the sixth 1,000-lb. charge, half-a-fusion charge of the coke was left out. This satisfactorily lowered the bed to the normal working level and seldom were the bars, cast at the start, beyond the working limits. With low-reactivity coke these precautions are found to be unnecessary; the bed has to be almost extremely high before the pick-up is appreciable.

While the great danger with the lighter cupola coke lay chiefly in the production of a high-carbon iron, which was sometimes in the region of 3.5 to 3.6 per cent., the danger with the dense coke lies more in the production of very low-carbon iron, which means that it is advisable to have the working bed higher when using dense coke to prevent any possibility of hard castings, due to low-carbon cause, by the bed becoming low. The fact that the different grades of coke available vary in reactivity, suggests that it is easily possible to obtain one, after a little experiment, to satisfy one's individual needs.

Cupola Bed Control

Returning to the control of the bed and similarly the carbon; prior to charging, the height must be carefully measured, and if necessary made up to the required level. With the cupolas in question, 24 in. above the tuyeres was found to be the maximum height permissible when using the lighter grade of coke, which in conjunction with the coating of lime gave a constant carbon content day after day in the first metal melted. Above this height the carbon rose in proportion.

Using dense coke, it is possible to exceed this height by 4 or 5 in. without producing excessively high carbon. This is a great advantage, as it permits of hotter iron at the start. The most suitable height at the commencement and the weight for each charge can only be determined by experiment to suit individual

foundries, and figures quoted here can only serve as a guide, but suffice it to say that the fusion charge must be accurately weighed for each charge.

It is important, too, that the charges of metal should not be large, as it would mean also correspondingly large charges of coke, which, as they reached the bed, would cause violent fluctuations in the height of the bed. To quote an example, if metal charges of 15 cwts. to 1 ton were the

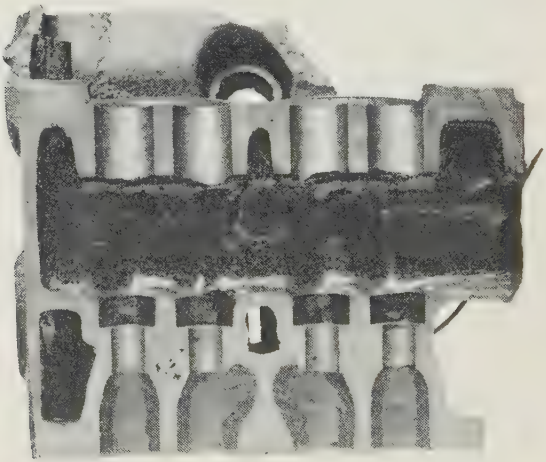


FIG. 5.—MONOBLOC SHOWN THROUGH VALVE GUIDE HOLES, SHOWING LIQUID SHRINKAGE CAVITIES (T.C., 3.56; Si, 2.2 PER CENT.).

practice, as is common with this diameter of furnace, then, using a metal-to-coke ratio of 10 to 1 would necessitate a coke charge of nearly 2 cwts., which would occupy a height in the shaft of approximately 12 in. Thus, when each charge came into position for melting, the height of the bed would vary accordingly, and would create unfavourable conditions, especially if a low-carbon iron were desired as the best position for the steel when charging is adjacent to the

coke. Under this category also comes the common, but bad, practice of adding extra coke to separate one mixture from another, as this will result in a temporary high bed, detrimental to uniformity. In this case, it would be preferable to drain the cupola and recharge.

Control by Keep's Tests

The test found to be the most suitable for a rapid and accurate determination of the amount of carbon present is found to be Keep's test. It is very simple, and consists of two bars, one 1 in. sq. transverse bar, which is broken on 12-in. centres, the other a $\frac{3}{8}$ in. sq. bar cast between the arms of a chill exactly a foot apart, which is

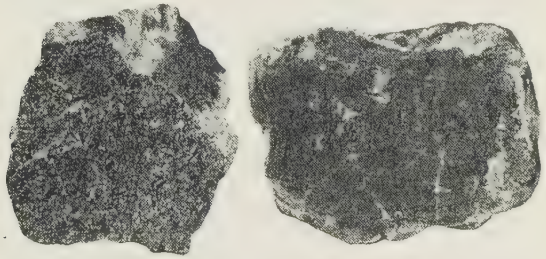


FIG. 6.—HIGH AND LOW REACTIVITY COKES. BOTH GOOD QUALITY.

inserted in the mould. On this smaller bar is measured the depth of chill and the lineal shrinkage. The fractures of both bars are also examined.

Any variation of the carbon is immediately reflected in the chill bar, which makes it quite a delicate test. Results can also be obtained rapidly, which is a great advantage, since, should the tests be beyond the limits, adjustments can be made almost immediately. The limits found to be most suitable for crank-case cylinders and heads, cast in green-sand moulds, are as follow:—Depth of chill, $\frac{7}{16}$ to $\frac{3}{4}$ in.; lineal shrinkage, 0.150 to 0.170 in. These correspond with a silicon of 2.1 to 2.3 per cent. in conjunction with a total carbon of 3.10 to

3.30 per cent. If the carbon rises much above 3.30 per cent., the increase is shown in the depth of chill, which falls proportionately to the increase of carbon; the shrinkage, however, appears to be unaffected. On the other hand, if the carbon falls much below 3.1 per cent., then the depth of chill increases, and with it the lineal shrinkage also.

A set of test-bars are cast every hour, and more often if unforeseen circumstances arise or if it is necessary to make an alteration in the mixture. This includes bars cast from the first and last ladleful of iron tapped in the morning and afternoon. The results of each set, that is, the depth of chill, shrinkage and classification of fracture of the small bar, is noted soon after it is cast on a board located not far from the melting section, so that the staff engaged on this section can keep an interest in their work.

Excessive Carbon Pick-up

A greater increase in carbon pick-up than that which is expected may generally be ascribed to three causes: (1) Bed too high, either as a result of incorrect measurement at the start or incorrect weight of the coke splits, (2) too much small coke in the bed and (3) insufficient limestone. Extremely low carbon is brought about by reasons other than insufficient weight of coke split, such as: (1) Collapse of the patching, which when fluxed away causes a settling down of the coke to fill the space formerly occupied by the ganister and (2) shutting off the blast for any length of time, such as during the lunch hour, also results in a low bed, owing to the gradual settling of the partly-suspended coke and slag caused by the relief of pressure.

Whilst collapse of the patching can be guarded against with care, shutting off the blast constitutes a definite complication unless suitable precautions are taken beforehand. With a continuous casting plant, when moulds are cast almost as soon as they are made, it is impossible to keep a reserve of moulds for the lunch

hour, during which period mould production has entirely ceased. It will be seen, too, that shutting off the blast for any length of time will at the re-start give rise to inconvenience with an unavoidable quantity of dull metal, which is, to say the least, uneconomical.

These two evils, that of low carbon and dull iron, can be overcome satisfactorily by adding extra coke—about half a charge has been found to be most convenient—prior to shutting down, so that its presence is felt in the bed just when the blast is shut off. With practice this can be timed fairly accurately. A precaution also advisable is to empty the well completely at the time of shutting down. The blast has been shut off satisfactorily this way, for as long as 1½ hrs., without the iron becoming too cold.

Tables I to VIII demonstrate the effects on the physical properties when the carbon exceeds the normal limits. Each table is representative of a full working day of about 8 hrs.' continuous melting, with tests taken at regular intervals. The first seven analyses were taken from records when this method of melting control was originally adopted, about two years ago.

The last one is of more recent date when the carbon was reduced to lower limits and the silicon raised to maintain easy machining qualities.

Conclusions

And finally, it has been the aim to eliminate as many technicalities as possible in an effort to make a normally dry subject more interesting to those who have not had metallurgical training and to those also who have not had personal experience in cupola practice.

In closing, thanks are due to Mr. Brown, foundry superintendent, and the Austin Motor Company for permission to present this Paper, and for the encouragement and facilities given. To Mr. Sheehan, also, for his help, as it was he who made this Paper possible by instituting this method of melting control for production castings.

DISCUSSION

Proposing a vote of thanks to Mr. Bamford, Mr. N. C. Blythe called attention to the statement that a charge of only 500 lbs. was used in a cupola 40 in. in dia., and, further, that the amount of coke charged was insufficient to separate the metal charges. He would like to know, he said, why orthodoxy was departed from in this way. He (Mr. Blythe) was responsible for a continuous-casting plant, and he found that under such conditions it was necessary to make up their minds to do one of two things. Either they must operate the cupola efficiently and run the plant to the tune of the cupola, or run the cupola to the tune of the plant. Unless his mental picture of Mr. Bamford's conditions was wrong, a fluctuating demand for iron had to be met, and it would be interesting to know how Mr. Bamford took care of that fluctuation. Mr. Blythe added that it was seldom, in these highly-competitive days, that a firm was prepared for precise operating details to be made public in such a way that the audience could return to their jobs and start producing iron with a closer carbon control.

Mr. E. C. Dickenson seconded the vote of thanks, which was heartily accorded, and Mr. Bamford acknowledged the compliment.

Mr. A. J. Shore asked whether, in the case of iron with controlled total carbon, it was still necessary to use chills.

Mr. G. R. Shotton, referring to Mr. Bamford's statement that there was little or no carbon pick-up in the well of the cupola, said he should have expected that there would be some. A high casting temperature was being used and his (Mr. Shotton's) experience of open-hearth melting was that total carbon was definitely increased, always dependent upon the temperature of the metal. The hotter the metal, the greater the pick-up.

Mr. J. Hird said he understood Mr. Bamford to say that porosity was aggravated by casting too hot. Did Mr. Bamford advocate keeping the iron in the ladle until it had cooled?

Mr. A. E. Lester asked for an explanation of how Mr. Bamford maintained the coke bed at the same height.

Efficacy of Keep's Test

Mr. T. R. Twigger, alluding to Keep's shrinkage test, said he gathered from Mr. Bamford that it had been found of considerable use in control. Personally, he had not seen much evidence to support the value of the shrinkage measurement. When installing an oil furnace, they particularly desired to have some ready means of control, and Keep's test was one of the first things that came into their minds. They found, however, that the variations in the actual amounts of shrinkage were exceedingly small. He would like to know if any particular care had to be taken in controlling the conditions under which the Keep's bars were cast, and whether Mr. Bamford considered the fracture was more important than the actual shrinkage. Had Mr. Bamford any experience of the use of soda ash in the cupola, in relation to carbon? In his own case, they had made some tests with soda ash and found that there was a tendency to lower total carbon when soda ash was used. Was that in any way akin to coating the coke with lime?

Hints on Cupola Control

Mr. L. W. Bolton said he was interested to hear that Mr. Bamford used a comparatively low-blast pressure on the cupola. He called it a "soft-blast cupola." For some years the British Cast Iron Research Association had been advocating the use of low-blast pressures, especially where steel was being melted. Mr. Bamford insisted on a thoroughly well-heated bed before charging commenced. Providing a bed with the whole of the coke red hot before charging took them half the

way in good cupola practice. He was not surprised to hear Mr. Bamford say that he was using small metal charges of 500 lbs. In normal working, where they were melting pig-iron and scrap of fairly similar composition, there would be greater coke economy with a heavier charge. But where they were melting such widely dissimilar constituents as steel and 3 per cent. silicon pig, small charges helped in maintaining a uniform supply of metal of the same composition. Mr. Bamford had mentioned that all the coke used in the charges was carefully weighed. He (Mr. Bolton) agreed that when they were using dense coke at one time and a fairly-open grain soft coke at another, weighing was necessary. He would like to know if Mr. Bamford took into account the possibility of coke being wet one day and dry another.

Carbon Pick-up

Mr. W. J. Molineux, referring to the carbon pick-up after the melting of the charges, said he thought Mr. Field had proved fairly conclusively that, even with a low-carbon iron, the carbon pick-up after the metal got into the well was almost negligible. Mr. Field, he thought, took samples of metal as it trickled past the tuyeres and compared it with the metal tapped from the cupola. It seemed reasonable to suppose that the carbon was picked up as the metal trickled through the incandescent coke in the melting zone. It was very difficult to introduce carbon into a bath of metal. Regarding casting temperature, he thought that, on the whole, what Mr. Bamford had said was perfectly sound. Had Mr. Bamford any experience of temperatures above the range he had named, say, 1,650 deg. C.? He (Mr. Molineux) had found that it was quite possible to get opposite effects with these high temperatures.

Mr. J. W. Gardom said Mr. Bamford had mentioned that he had taken samples of steel from just above the bed and found that there was a certain amount of skin penetration of the carbon. He would be interested to know how

Mr. Bamford got hold of the sample just above the bed.

Mr. E. Hunter inquired why 2.2 silicon was used instead of standard silicon iron.

Refined Iron Charges

Mr. H. G. Hall suggested that low-silicon iron was greedy for carbon, and took it up readily. Some years ago, he said, he was connected with a cylinder foundry, and he could confirm Mr. Bamford's remarks on the subject of small charges in the cupola where they wanted to produce high-class cylinders. They were using, at the time, a refined-iron charge with a small steel addition, and, if anything, their carbon results were more uniform than Mr. Bamford's, possibly due to the fact that they were using a more uniform charge.

Mr. E. W. Wynn said his experience definitely was that it was difficult to put carbon into molten cast iron. He thought the steel must pick up some of the carbon before it melted. In his opinion, the testing of their cupola working by fracture was rather difficult. He imagined that the amount of graphitisation was dependent not only on the carbon and silicon content, but also on the type of metal which they were charging into the cupola.

Shrinkage and Chill Depth

Mr. W. G. Morgan said his firm applied Keep's test, and their results were somewhat different from those of Mr. Bamford. Their silicon was about 1.9, with a total carbon of about 3.3. The shrinkage was 0.15 or 0.16. The chill came down to $\frac{1}{4}$ in. and the combined carbon went to 0.65 or 0.68 per cent.

Author's Reply

Replying to the questions, Mr. Bamford said Mr. Blythe had suggested that a 500-lb. charge was rather low, and wanted to know how synchronisation was obtained. In his (Mr. Bamford s) opinion, it really paid to reduce the charge and

increase the capacity of the well in order to obtain better mixing. By so doing they obtained a thoroughly good mixture, and at the same time there were always five or six charges melted before they tapped out. They could adjust the blast to suit any degree of melting, while the carbon pick-up showed no difference, unless, of course, they had a high bed, when they would expect a high pick-up. As to the removal of chills from the castings, his reply was that they almost invariably removed them. With regard to Mr. Shotton's comment on carbon pick-up in the well of the cupola, he could only say that they had not experienced it. Samples of iron had been left in the well of the cupola for about two hours and, when they had tapped out, it had never been any higher in carbon than it was just before shutting down the blast, even when the iron had been really hot—1,400 or 1,500 deg. C.

Soundness and Time Factor

On the subject of porosity, Mr. Hird had asked if they held the metal in the ladle before casting in order to get sounder iron. His answer was that they did in the case of a small, thick casting, but on crankcase jobs, which were fairly thin, they poured straight away. Mr. Lester had inquired how they maintained the height of the bed during the run. If the bed began to drop it was indicated by additional sparking of the metal when tapped. Further, chill was immediately increased in the bar. Mr. Twigger had referred to Keep's test and asked if it was found that the fracture was more important than the shrinkage. In the case of a large casting, the shrinkage would be the principal feature, but with a small casting of about 1 ft. it did not matter. A fracture was the quickest guide. On the matter of soda ash in relation to total carbon, judging by appearances through the tuyeres it did not seem that the coke was covered by the soda ash. In their own case they had added soda ash to the charges for the last six months and found there was no difference.

In reply to Mr. Bolton, Mr. Bamford said there was such a thing as analysing coke for the water content. This was done twice a day in wet weather, and adjustments were made accordingly. To Mr. Gardom, who inquired how the sample of steel was obtained just as it entered the bed, his reply was that in the case in question the bottom was dropped just before melting finished and the steel recovered. Mr. Hunter had asked why they used 2.2 silicon instead of standard silicon iron. His reply was that if they got down to 1.7 or 1.8, probably, with dry sand moulds, they would have white castings. Mr. Hall was of opinion that low silicon increased the carbon pick-up. His own (Mr. Bamford's) view was that the pick-up was due to a high bed more than to anything else. They must keep the level of the coke-bed constant, whatever carbon was being used. His reply to Mr. Morgan's criticism was that they had always found a chill in the region of $\frac{3}{4}$ in. corresponded with shrinkage of about 0.16 in.

Sheffield Branch

THE TECHNIQUE OF CHILLING

By J. Roxburgh (Member)

It is proposed to deal with chilling and densening, as it is well known that there is a definite demand for chilled castings in modern industry, and, also, densening is becoming increasingly favoured by manufacturers of specialised castings. So, initially, attention should be directed to the "chilling irons" and to the consideration of why these irons, under certain conditions, are able to throw a chill on a casting. It is generally accepted that certain irons possess this property to a greater degree than others, and cold-blast iron, which has a very wide application in the manufacture of chilled rolls, is a notable example.

It is, of course, generally understood that certain grey and mottled irons, when poured into an iron mould, will "chill," and it is found from experience that, when the silicon content is approximately 1.7 per cent. in an ordinary iron containing up to 0.9 per cent. Mn and 0.1 per cent. S, a bare chill will be shown on a test-piece, cast on a chill, and that, as the silicon is reduced, so the depth of chill is increased, until with approximately 1 per cent. silicon, for example, a chill of $\frac{3}{4}$ in. could be obtained. It is also recognised that silicon is the most important factor governing the amount of combined carbon present in an iron, and, for this reason, may be said to be the chief constituent in determining the depth of chill as revealed on a test-piece.

To the uninitiated, it would be perplexing to know how to set about obtaining a chill, and so, considering an iron with a silicon below 1.7 per

cent., a chill could be thrown when the iron is:— (1) Low in total carbon, in which case such an iron has a higher initial freezing point and consequent less separation of graphite; (2) high in sulphur. The carbon is therefore retained in the combined form by the portion of sulphur not associated with the manganese, and it is that portion which crystallises with the carbide, which is mainly responsible in preventing the separation of graphite by making the carbide stable; (3) low in silicon. As stated above, the silicon, as it is reduced below 1.7 per cent., gradually increases the chilling properties, due to the lesser dissociation of the carbide into graphite and pearlite; (4) high in manganese. Above 1 per cent. manganese tends to keep the carbon in the combined state and form carbides, thus accentuating the chilling properties of the iron; and (5) high in chromium. It appears that a double carbide of iron and chromium is formed with a hardening effect on the iron, which tendency is also noticed particularly in the chilling proclivities of the metal.

Thus, it is obvious that, in the above five examples, it is possible to obtain quite different types of "chill," and the chilled surfaces are definitely of a different character in regard to microscopical structure and physical properties, and must therefore exert considerable influence on the behaviour of the castings in service. For instance, with a low total-carbon chilled iron, it is possible to obtain a surface hardness of only 50 Shore, whilst, with a high-sulphur chill, up to 0.2 per cent., the Shore reading can be 70. Again, with high manganese, above 1 per cent., figures of the magnitude of 65 to 70 Shore can be obtained, and with chilled iron, containing sufficient chromium, readings of 80 Shore can be reached.

The Back of the Chill

It is all very well being able to obtain a chilled surface on the casting, but, at the same time, too great emphasis cannot be laid on the importance of the resultant background. It

will therefore be appreciated that each of the above elements exerts its own individual effect on the background of the structure. It is found, for example, that with a low total carbon, the chilled portion is usually backed up with a depth of mottle, gradually merging into a dark grey background, all denoting strength and toughness.

On the other hand, with shallow high-sulphur chills, a very defined chill is obtained, with very little mottle between the white area and the background, while with deep chills there is a tendency to be mottled throughout. Such a structure definitely lacks strength, and is of a brittle nature. In the case of high-manganese chills, the manganese tends to increase the strength of the iron, and also the resistance of the castings to heat strains, and hence diminishes the danger of surface cracks. An interesting application of a high-manganese chilled casting is one where the casting has to withstand repeated impact, *e.g.*, crusher jaws and hammer pellets. The chill produced with high manganese extends deeply into the juxtaposed grey portion.

Chromium Chill

With regard to a chromium chill, the carbides appear to penetrate into the background in streaks, and if the chromium content is high, these white streaks extend very often to the centre, where they seem to form a cluster. These streaks definitely weaken the background, and, in order to increase the strength of the iron, it is customary to add molybdenum or nickel, or both, to eliminate the mottle in the background. Naturally, the depth and quality of chill required on a casting depends on the service for which it is intended. Many different depths and types of chill are therefore required on chilled rolls; in the case of strip rolls, sheet rolls, tinplate rolls and plate rolls a depth of $\frac{5}{8}$ in. to $\frac{3}{4}$ in. is good practice, as a particularly strong roll is demanded. For hot breaking-down rolls, where a good finish is not so essential, a

low total carbon, approximately 3 per cent., and fairly low sulphur, is suitable, as such a roll is able to withstand temperature and shock. On the other hand, for cold finishing, a much harder surface roll is required to obtain a polished surface on the rolled material, and to-day, alloy rolls are more in fashion, whereby, with the addition of chromium and molybdenum and nickel, Shore hardnesses of the order of 80 are obtained. In this connection, it may be mentioned, it is possible with alloy-steel rolls, suitably heat-treated, to obtain regularly figures of 100 Shore.

Chill Depths for Various Uses

With section rolls, the depth of chill varies according to the size of roll and the section to be rolled, so variations of chill from $\frac{3}{4}$ in. to as much as $2\frac{1}{2}$ in. are asked for. As the sections are generally machined out of solid, the hardness decreases in the bottom of the grooves, but at the same time a fairly strong roll is required. High-sulphur rolls are extensively used for section rolls where there is no great temperature or stress on the rolls. Caution must be exercised, as, if the roll be brittle due to a deep chill and too high sulphur, cracking or premature breakage may occur. For very deep sections, a low total-carbon, low-silicon and lower-sulphur iron has proved better in service. With wire rolls, with small grooves, and consequently little stress, a deep chill is used with confidence, and a sulphur content of 0.2 per cent. would prove quite safe in service.

For rolls of rubber, linoleum, paper, seed, flour, etc., generally speaking, a maximum of 1-in. chill should be aimed at when they are solid, but for hollow rolls $\frac{3}{4}$ in. is ample. Where refining of material is carried out under pressure, a much stronger roll is required, and $\frac{1}{2}$-in. chill is quite sufficient. In connection with paper, seed and flour rolls, a hardness of 72 Shore is demanded by the customer, and, with the small-diameter rolls, this can be achieved by the use of a suitable iron, with high total carbon in the

region of 3.6 to 3.7 per cent., as the main feature, whilst, particularly in the case of paper rolls, which are usually of great length with a wide variation of diameter, alloys are resorted to, mainly chromium and nickel or molybdenum. The surfaces of such rolls must be extremely hard, high polished and absolutely free from pinholes or any defects whatever.

Effect of Thermal History

The ultimate physical and microstructure of cast iron depends not only on its composition, but on the cooling rate, and, by the acceleration or prolongation of this cooling rate, so will result different structures. With chilling, the cooling rate is artificially accelerated, and, in the case of the formation of an actual depth of chill, the iron is frozen immediately, all the carbon in the white area being retained in the combined form, whilst, with densening, the time for the separation of the graphite into large flakes is curtailed, with the result that the graphite formed is in a finer state of division. So that, in the main, it is the form in which the carbon exists after chilling which is the important feature, and the effect of the other elements in the cast iron is shown in their influence on the stabilisation or otherwise of the carbide, and also, due to their presence, the actual degree of hardness of the surface may vary.

In a chilled roll, there are three different zones, the white zone, the mottled zone and the grey background. Tensile strains are set up after solidification has commenced, due to the difference in contraction between the three types of iron and the different temperatures obtaining in the three zones, and also it is accepted that graphitisation takes place with expansion, and for these reasons it is important that the white area formed should be strong enough and set quickly enough to resist all these forces. Sometimes vertical cracks are found on a chilled roll, after removal of the casting from the mould, and these are attributable definitely to metal, and are very often due to " uneven chill " or

the roll, cracking taking place where the chill is shallowest. On the other hand, a horizontal crack points to some obstacle due to moulding practice, to the vertical contraction. If, for instance, two chills are used to form the length of a roll, cracking at times is found at the joint, and this defect might be traced to the fact that the top chill has not been set correctly at right-angles to the bottom chill, or might be slightly larger, or it is possible for the top neck even to cause interference with contraction due to a swell on it or to insufficient taper having been allowed, or again to not having been "eased" soon enough.

Again, if an iron has too long a freezing range, and certain constituents are present in a larger percentage than usual to cause graphitisation, it is possible for such an iron to continue "working" inside the mould for a long period, with the ultimate effect of causing graphite spots to be formed well into the white area, and, particularly in the case of irons, fairly high in manganese up to 0.7 per cent., on machining the surface of the roll, graphite spots can be detected on the chilled surface itself. It is usual, therefore, in chilled rolls to have a low-manganese iron or one with a manganese content above 1 per cent. to obtain a definite fixed chill.

Effect of Elements on Chill

It is now necessary to consider the effect of the various constituents on the depth of chill as indicated on a chilled test-piece. From experience, it has been found that the lower the total carbon, the deeper the chill thrown, and, following from that the raising of the total carbon will cause a reduction. Again, all other constituents being constant, the lower the silicon, the deeper the chill, so that in the event of the chill depth, as shown on the test-piece, being greater than desired, powdered ferro-silicon or, on the other hand, a definite quantity of soft iron, may be added to the metal in the ladle. The composition of the soft iron, of

TABLE I.—*Mixtures for a 1-in. Chill.*

Cwts.		T.C.	Si.	Mn.	S.	P.
	(1) *Suitable for a Hydraulic Cylinder.*					
10	Cylinder scrap	3.2	0.9	1.2	0.095	0.4
5	Machinery scrap	3.2	1.5	0.9	0.070	0.6
5	Cylinder iron	2.8	1.0	1.6	0.050	0.3
20	+ 14 lbs. FeMn (80 per cent.)					
	Calculated analysis	3.10	1.07	1.7	0.077	0.42
	Actual analysis	3.20	0.90	1.20	0.10	0.42
	(2) *Could similarly be used for a Hydraulic Cylinder.*					
9	Steel	2.8	—	0.5	0.05	0.05
12	S.S. scrap	3.2	1.7	0.8	0.09	0.50
2	Forge	3.4	1.0	0.9	0.095	1.2
2	No. 4 Comm.	3.3	2.0	0.9	0.05	1.2
25	+ 35 lbs. FeMn (80 per cent.)					
	Calculated analysis	3.08	1.07	1.7	0.073	0.45
	Actual analysis	3.20	0.90	1.20	0.10	0.45
	(3) *Suitable for Chilled Rolls for Sections, etc. Silicon would be altered to increase Depth of Chill.*					
5	Chilled scrap	3.30	0.90	0.33	0.160	0.5
10	Air furnace	2.90	1.10	0.45	0.130	0.40
5	Iron	3.40	1.10	0.55	0.090	0.55
20	Cold blast					
	Calculated analysis	3.12	1.05	0.44	0.128	0.47
	Actual analysis	3.30	0.93	0.33	0.160	0.47

(4) *Suitable for Chilled Safe Plates.*

Cwts.		T.C.	Si.	Mn.	S.	P.	Cr.
10	Swedish	4.0	0.6	0.3	0.03	0.05	
5	Chilling	3.3	0.5	0.5	0.07	0.4	
5	Iron						
5	Cold blast	3.4	1.0	0.6	0.08	0.5	
20	+ 35 lbs. FeMn (80 per cent.)						
	Calculated analysis	3.68	0.68	0.43	0.053	0.25	
	Actual analysis	3.75	0.58	1.20	0.08	0.25	

(5) *Suitable for Chilled Sheet Rolls, etc., where Silicon would be reduced.*

Air furnace	3.00	0.85	0.35	0.120	0.50

(6) *As No. 5.*

Air furnace	3.00	0.8	0.26	0.08	0 50

(7) *Limited Application. Small Section Rolls.*

All chilled scrap	3.40	1.3	0.26	0.21	0.5

(8) *Suitable for some Heat-resisting Castings.*

Cwts.		T.C.	Si.	Mn.	S.	P.	Cr.
8	Steel	2.8	—	0.5	0.05	0.05	
6	Ingot mould scrap	3.5	2.0	0.7	0.06	0.06	
6	Hematite	3.8	2.5	2.0	0.05	0.05	
20	+ 14 lbs. FeChrome (70 per cent.)						
	Calculated analysis	3.31	1.35	1.01	0.053	0.053	—
	Actual analysis	3.45	1.20	0.7	0.08	0.06	0.35

course, should be known, so that a calculation can be made in order to determine, for example, that 1 cwt. of soft iron, when added to 1 ton of a definite chilled iron, would reduce the depth of chill by, say, $\frac{1}{4}$ in., or, in other words, the addition of 0.06 per cent. silicon.

An increase in sulphur definitely increases the depth of chill on a test-piece, and, where the test is lower than required, some people resort to adding powdered ferrous sulphide to the metal to increase the depth of chill. This element sulphur must be considered along with manganese, as an alteration of either constituent will influence the depth of chill. An increase of manganese up to 0.9 per cent. reduces the depth of chill, but beyond 1 per cent. a manganese chill is obtained, as explained previously. Thus, it is possible with an iron containing low silicon, low sulphur and 1.5 per cent. managanese, to obtain $1\frac{1}{2}$-in. chill on a test-piece; yet, on the other hand, with a low silicon, 0.15 per cent. sulphur and 0.30 per cent. manganese, a similar chill could be obtained. Phosphorus, incidentally, has very little influence on the actual chilling of an iron.

Supposing it is desired to obtain, for instance, 1-in. chill on a test-piece, it is submitted that this can be done with, for example, eight different mixtures of iron and ultimate compositions of irons, as set out in Table I.

Thus there are shown eight different mixtures, varying in analysis from 3.0 to 3.75 per cent. total carbon, 0.58 to 1.3 per cent. silicon, 0.26 to 1.20 per cent. manganese, and 0.08 to 0.21 per cent. sulphur, and one mixture with chromium, and yet all showing approximately 1-in. chill on a test-piece.

Now it is all very well being able to obtain 1-in. chill, or whatever depth of chill is aimed at on the test-piece, but if, in addition, it is required to guarantee a certain depth of chill on a casting, made from such a metal, then here is a matter most difficult of achievement, and the results obtained immediately reveal any discrepancies or variance in the control exercised.

In other words, the control of the loss of chill from the test-piece to the casting is of supreme importance, and, before proceeding to deal with this matter in detail, it is proposed to give particulars regarding the test-piece, to which frequent reference has been made.

Making Chilled Test-Pieces

The test-piece itself measures 6 in. by 6 in. by $1\frac{1}{8}$ in., usually made in a core, and placed on an iron slab, 8 in. by 5 in. by 2 in. thick. This slab is heated, coated with blacking, and then the metal is poured into the test-piece and allowed to remain for 5 min. It is then withdrawn, cooled in the air and finally quenched in cold water. Every care should be taken with the carrying out of these tests, otherwise confusing and indefinite results will be obtained. For instance, the higher the temperature of the metal when cast into the test-piece, the deeper the chill, and so the test should be poured each time with metal at approximately the same temperature. Care, too, should be exercised not to accelerate unduly the quenching of the test-piece, as cracking may occur, and it is also better to allow the test-piece to cool down to a definite temperature before commencing to quench, so that, particularly in the case of deep chills, the depth of chill can be read more easily and a better background to the chill be obtained. In fact, all conditions should be as near standard as possible in order to make the results comparable. This size of chill test-piece is suitable for indicating depth of chill where silicons below 1.7 per cent. are involved.

In reviewing the possible variables which will influence the loss of chill from test-piece to casting, the following suggest themselves for consideration:—(1) Composition of metal; (2) temperature of casting; (3) mass of casting to be chilled; (4) thickness of iron mould; and (5) thickness of blacking applied to iron mould. With regard to composition of metal, which, undoubtedly, is the factor exerting the greatest

influence, it can be stated that it is possible for $1\frac{3}{4}$-in. depth of chill to be thrown on a test-piece by two different mixtures of iron, and yet on the same casting, cast under identical conditions, there would be $1\frac{3}{4}$-in. chill in one case, *i.e.*, no loss of chill, and on the other $\frac{3}{4}$-in. chill, *i.e.*, 1-in. loss of chill. A cupola-melted cast iron of the following composition:—Total carbon, 3.3; silicon, 0.85; manganese, 0.32; sulphur, 0.20; and phosphorus, 0.5 per cent., would give no loss of chill, whilst an air-furnace iron containing total carbon 2.90, silicon 0.70, manganese 0.32, sulphur 0.120 and phosphorus 0.5 per cent. would lose $\frac{3}{4}$-in. chill under the same conditions.

Mn : S Ratio and Loss of Chill

If the total carbon, silicon and phosphorus are constant, it is possible to alter the loss of chill from test-piece to casting by varying the balance between the manganese and sulphur. If the sulphur be kept constant and the manganese content is progressively raised up to 0.9 per cent., the loss of chill from test-piece to casting is increasingly greater, but, on the other hand, if the manganese remains constant below 0.9 per cent. and the sulphur is gradually increased, the loss of chill is diminished. It must be remembered, however, that above 1 per cent. manganese increases the depth of chill on the test-piece, and, as the content is raised, so the loss of chill is diminished.

The six analyses shown in Table II would give approximately $1\frac{1}{2}$-in. chill on a test-piece, but the manganese-to-sulphur ratio varies in each case with subsequent effect on the loss of chill to the casting, as instanced on a 16-in. dia. chilled roll.

The fourth example is an air-furnace iron, and it has been found, from experience, that, if the manganese is raised to 0.42 per cent., all the other constituents remaining the same, it is possible to lose as much as $1\frac{1}{4}$-in. chill, so that if a deeper chill were required on the roll, it would have to be cast with an iron showing a deeper chill on the test-piece, by lowering the silicon.

TABLE II.—*Influence of Mn : S. Ratio on Loss of Chill.*

	T.C.	Si.	Mn.	S.	P.	Ratio Mn : S.	Loss of chill.
1	3.3	0.8	0.25	0.16	0.5	1.57/1	Nil
2	3.3	0.85	0.32	0.20	0.5	1.6/1	Nil
3	3.3	0.75	0.32	0.16	0.5	2/1	$\frac{1}{4}$ in.
4	2.8	0.70	0.32	0.12	0.5	2.66/1	$\frac{7}{8}$ in., extra loss due to low T.C.
5	3.3	0.65	0.45	0.16	0.5	2.81/1	$\frac{5}{8}$ in. to $\frac{3}{4}$ in.
6	3.3	0.60	0.32	0.08	0.5	4/1	1 in.

Lower total carbon gives a deeper chill on the test-piece, but, due to this, it has been found that a greater loss of chill occurs from the test-piece to the casting. If the total carbon is as high, for instance, as 3.7 per cent., the chill on the test-piece is shallower, but less loss occurs in the casting.

Alloyed Rolls

In cases where chromium is added to chilled iron, in order to obtain a similar depth of chill to that of an iron without a chromium addition, the silicon content must be increased. For instance, a 1½-in. chill on a test-piece could be given with an iron of the following composition: Total carbon, 3.4; silicon, 1.10; manganese, 0.33; sulphur, 0.16; phosphorus, 0.5; and chromium, 0.4 per cent. Chromium definitely prevents the loss of chill from test-pieces to the casting, and at times, with higher percentages, the depth of chill has actually increased. Where nickel and chromium are alloyed together in aiming at the same depth of chill on a test-piece, the silicon content should be determined by making allowance for the nickel present.

Molybdenum may be employed as the only alloy present, and a typical analysis of a strip or sheet chilled roll is:—Total carbon, 3.0; silicon, 0.60; manganese, 0.27; sulphur, 0.06; phosphorus, 0.4; and molybdenum, 0.25 per cent. Claims made for this type of roll are that it is stronger, there is less breakage and less frequent dressing, and a better finish on the rolled products is obtained. Molybdenum apparently does not increase the depth of chill, but toughens both the chilled surface and the matrix.

Casting Temperature

With regard to temperature of casting the second variable, this temperature naturally falls within well-defined limits, as "burning-on" would result if the temperature were too high, whilst casting at low temperatures would interfere with running and would cause pinholes, too. For small chilled rolls up to 26-in. dia., a range from 1,240 to 1,270 deg. C. is usual, whilst for

larger rolls above 26-in. dia. 1,210 to 1,240 deg. C. is suitable. In any case, the metal should be melted as hot as possible and allowed to cool down to the desired temperature, as badly-melted iron for chilled rolls is fatal and should be scrapped straightaway. It has been shown that the lower limit of casting temperature gives a slightly deeper chill on the casting, but, as it only amounts to about $\frac{1}{16}$-in. increase, this phase of the subject is hardly worth serious consideration. It is, however, best to cast at the higher limit of temperature in an endeavour to obtain a cleaner roll.

Mass and Chill

The mass of the casting to be chilled naturally enters into this question of loss of chill, and so it is found, with smaller chilled rolls, the loss is less than with larger castings, and this is especially marked where deep chills are concerned. With the same iron, when casting, for instance, a 10-in. roll and a 24-in. roll, the latter roll should be cast at least $\frac{1}{8}$ in. deeper on the test-piece than the former to obtain the same depth of chill. Regarding the thickness of the iron mould, the first point of importance to be stressed is that it is primarily a question of strength and stiffness, in the case of chilled rolls. Rather err on the thick side, as thin chills in contact with the metal will crack, so that essentially it reduces itself in the first place to having sufficient strength in the mould to take care of the expansion and contraction strains. It must be realised that a very short time after casting, the walls of the mould have no further effect on the cooling of the casting, and that, increasing the thickness of the walls beyond a given measurement has no effect on its chilling. Chills for a 10-in. roll are usually 6 in. thick, whilst a suitable thickness for a 30-in. roll would be 11 in. thick.

The last variable, the thickness of blacking applied to the iron mould, definitely has only a slight effect. The iron mould is usually coated with wet blacking, mixed with molasses, the

idea being to obtain a uniform thickness of blacking, as thin as practicable, to adhere to the chill whilst casting. If the blacking is unduly thick, it might affect the loss of chill to the extent of $\frac{1}{8}$ in. maximum.

So much for that aspect of "chilling" where an actual depth of chill is obtained on a casting, but, as a result of the study of the details of this practice, there has been developed what are known as "bastard" rolls and "half-hard" rolls. With regard to the former, these are usually cast in the same chills as are used for chilled rolls, but are made from an iron giving only $\frac{1}{8}$ in. to $\frac{1}{4}$ in. on the test-piece. The result is that the roll itself, on machining, only reveals a skin chill, which, when machined off, shows a very close-grained structure, which penetrates for a depth of 2 in. to 3 in., and is suitable for section rolls, the grooves being machined out of the solid. These rolls are used for breaking down, but are somewhat limited in their application.

A "half-hard" roll demands particular attention to the composition of the iron itself, as well as to the densening effect of the iron mould. For instance, a chill, as used for chilled rolls, could be struck up with $\frac{1}{4}$ in. loam on its surface, due regard, however, being paid to "venting," and permit of iron giving $1\frac{1}{2}$-in. chill on a test-piece to be used and still give a close-grained iron, easily machined, and densened to a depth of, maybe, 4 in. Likewise, with such rolls with the grooves actually cast, in which case iron bricks approximately the shape of the grooves are built in the mould and coated with a $\frac{1}{4}$-in. loam, the quality of the roll, depending on the very close structure obtained, is greatly enhanced.

Densening

This principle of densening, by the use of chills of a definite shape and thickness, with a view to obtaining a closer structure of iron in a casting than would be the case by the use of sand alone, has been successfully applied to castings for other

industries. For instance, wheel blanks are cast in circular chills and the teeth, when machine-cut are stronger and tougher. Better service is ensured with tyre and glass moulds when cast on a chill. To-day the machine-tool maker often specifies that the slides be densened by chills and goes so far sometimes as to demand specific Brinell hardness numbers.

When all is said and done, if it is appreciated that, in chilled work, iron moulds of at least 6 in. thick are in common use, that it is submitted that, as densening has arisen definitely from the practice of chilling and chilling irons, the principles involved need only be taken the necessary step further to provide the fundamentals for the practice of densening.

Densening is again resorted to where there are different sections of metal to contend with in a casting. What is really important is the acceleration of the period of cooling in some particular place. If one could obtain uniform cooling conditions of both thick and thin sections then the demand for the thin section for more metal from the thick section would cease. With a hydraulic cylinder, for instance, there are sometimes places where large ribs, brackets or feet join the casting, causing abnormal sections of metal and, despite the fact that a low-carbon, low-silicon, close-grained iron is used, the bore, when machined, reveals sponginess in the vicinity of these sections. Such is the sponginess which, very often, can be eliminated by the careful application of denseners. One can also do much, in this connection, by the use of alloys, particularly nickel.

Chill Tests and Machinability

For ordinary dry-sand castings, the chill test, as described, can be applied and prove very helpful, but it is as well to remember that such tests are comparative and can only be correlated where similar mixtures of iron are used and similar compositions sought. Composition is not everything, but is merely a guide, and after all it is the ultimate structure obtained which is

the important point. Chill tests are particularly useful where the machining qualities of a casting are of vital importance. For instance, it has been found from experience that an iron containing total carbon 3.2, silicon 1.2 and chromium 0.7 per cent., showing $1\frac{3}{8}$ in. depth of chill on a test-piece, would permit of machining of a casting 1 in. thick, cast in a dry-sand mould. Any lowering of the total-carbon content, reduction of the silicon or increase of chromium would render the iron unmachinable with the facilities available in this particular instance. Even with the same mixtures on the cupola, an analysis cannot be guaranteed as the melting conditions vary from day to day and so, in this case, if a chill test be taken, it may be that the depth of chill is in excess of $1\frac{3}{8}$ in., and so soft iron may be added to restore the balance of total carbon, silicon and chromium, thereby ensuring the machinability of the casting. If the casting had been poured without viewing the test-piece, a waster would have been inevitable.

Another application of the chill test in dry-sand work, where similar irons are made use of, is the correlation of the depth of chill to section of casting for high-grade work, where as close a structure as possible is demanded. For instance, a casting 3 in. thick would have a better structure when cast with an iron containing 1 per cent. silicon than one of 1.5 per cent. silicon content and a chill test would show 1 in. probably in the first case and only $\frac{1}{4}$ in. in the second, so that the chill test would reveal the suitability of the iron, before casting, for the particular job. Often, too, the exact nature and analysis of the scrap in the yard is not known, and after incorporating a percentage of this in a definite mixture, a chill test can be taken to indicate, knowing the other irons used, a certain approximate physical structure and maybe some idea of the analysis. Where similar irons are used, and the resultant total carbon, manganese, sulphur and phosphorus in the metal is fairly constant, Table III, which can only be

approximate, will be found useful in the endeavour to obtain a close structure on high-grade dry-sand castings.

TABLE III.—*Silicon Content, Section and Chill Test.*

	Si. content.	Minimum section of castings in in.	Maximum chill test in in.
1 ..	1.5	$\frac{1}{2}$	$\frac{1}{4}$
2 ..	1.3	$\frac{7}{8}$	$\frac{1}{2}$
3 ..	1.15	$1\frac{1}{2}$	$\frac{3}{4}$
4 ..	1.00	$2\frac{1}{2}$	1
5 ..	0.80	4	$1\frac{1}{4}$
6 ..	0.60	6	$1\frac{1}{2}$

In conclusion, it is emphasised that it has not been the author's intention to discuss the manufacture of chilled rolls, but to emphasise certain essential principles of chilling and densening, at the same time indicating the degree of control necessary for success.

DISCUSSION

The CHAIRMAN (Mr. J. E. Hurst), in opening the discussion, said that the Paper was of vast importance, not only to those engaged in the manufacture of chilled rolls, but to everybody else who was interested, particularly in the chilling periods of irons and the application of chills and densening. He asked if Mr. Roxburgh could tell them how the depth of chill on the chilled roll itself was measured. He had given them many results dealing with the ratio of the chilled depth on the test-piece to the chilled depth on the roll.

MR. ROXBURGH, in reply, explained that for the proving of the depth of chill on a chilled roll, usually the roll was put in a lathe, the head put into the chocks, and then it was centred at the other end, and a tool was run down the bottom end of the barrel. A tool was also run down at the top end, and in that way they machined at the ends of the roll where it

came down on to the neck, and ran down the ends until they came into the mottle and then into the background. They very often had to put a radius tool in, because there was a radius on the neck. They ran down in that way, and that revealed the depth of white iron, mottle, and then the background, and then they measured from the outside of the barrel down to the mottle. There was usually $\frac{1}{2}$ in. allowed on the diameter of a roll for machining, which meant that, if they measured, say, $1\frac{1}{2}$ in. of white iron, they would subtract $\frac{1}{4}$ in. for machining, and that would give them $1\frac{1}{4}$ in. of finished chill. It had been found that it was better to leave more material (in the length) at the top end of the barrel to machine off. At the bottom end they only machined off $\frac{1}{4}$ in., but at the top end, very often, $\frac{3}{8}$ in. or $\frac{1}{2}$ in., and they generally ran the top neck off with a radius from the barrel. Unless extra machining was allowed, they got a less depth of chill at the top end of the roll than at the bottom. To test the correct depth of chill on the roll, they usually proved the bottom end.

Half-Hard Rolls

Mr. P. Green said he was very interested in the half-hard rolls that Mr. Roxburgh mentioned. In talking about them, he mentioned that suitable venting arrangements should be made—presumably, to take the gas away from the quarter- or half-inch coating of sand. He should like the author to give them any further information he might have with regard to that particular method. He could imagine that it was rather a difficult job for moulders to put $\frac{1}{4}$ in. of loam on a chill, and it would be interesting to know how this loam was applied.

Another interesting point Mr. Roxburgh mentioned was that of giving the depth of chill and correlating that with the thickness of casting which had to be made. He was not quite in agreement with Mr. Roxburgh there. It was certainly very useful to take a chill test and say that would produce a definite structure of a

given section of casting, but he thought that what Mr. Roxburgh had not pointed out was that it depended upon what that casting had to withstand, whether it was shock, heat, or wear. He thought that should be stated, because he could quite see that different depths of chill should be used for the different requirements of the work that the casting had to do. He was also interested in the analysis Mr. Roxburgh gave for, he thought, strip metal rolls and sheet metal rolls, containing, he believed, about 0.2 per cent. molybdenum. He took it from the figures given that that was an air-furnace composition, and he was interested in how the molybdenum was added to the metal. Also, he had some recollection of a recent Paper by Mr. Roxburgh, in which it was stated that there was some difficulty in actually analysing the molybdenum content, and he wondered whether the 0.2 per cent. now mentioned could be taken as accurate.

Factors Influencing Chill Depth

Mr. Roxburgh said, with regard to the half-hard roll, there were several methods of taking care of the venting. As one of them happened to be a patent method of doing it, perhaps he would be out of order in indicating to Mr. Green how it was done. But, first of all, when they conducted some experiments, they got an ordinary chill and clay-washed it, and then procured some lamp wick (string would have done just as well), and laid this on the inside of the surface of the chill at, say, $\frac{1}{2}$ in. apart all the way round, rubbed the loam on the chill to a thickness of $\frac{1}{4}$ in., and then put the chill into the stove, and the lamp cotton was burnt out. That took care of the venting in rather a crude way. The other method depended on machining saw cuts in the chill, of a certain width and depth and certain distances apart, whereby the escape of the gases was ensured. Then the striking-on of the loam was carried out in exactly the same way. The chill was clay-washed, and loam was rubbed on to the chill, and it was struck with

a striking board to the required diameter, allowing $\frac{1}{4}$ in. of loam on the chill. But at the same time he should like to give a warning that, with bigger rolls, the ordinary loam was not sufficiently refractory; a very special sand had to be used in order to withstand the temperature of the metal.

He quite agreed with Mr. Green's remarks regarding the correlation of the depth of chill, the silicon content, and the section of metal. Mr. Green had made quite a good point that definitely this correlation did depend on the service for which the casting was intended. What he (the speaker) had more in mind was an engineering casting, for instance a hydraulic cylinder or some casting which had to stand pressure tightness—a steam-hammer cylinder, or a hydraulic cylinder, or some engineering casting of that description, where a particularly close structure was required for pressure tightness.

Mr. Green's other reference was to a sheet roll containing 0.25 per cent. molybdenum. When they made their first metal containing molybdenum they sent it to an independent source for analysis, and, although they had only added sufficient ferro-molybdenum to give 0.25 per cent. in the actual casting, it was reported as 1 per cent. That was absolutely impossible, but they found after some research that it was quite an easy matter to make a mistake in the actual analysing of the metal, and eventually they standardised a method whereby they could get a correct percentage and be sure of it. Now, the molybdenum was added to the air furnace in the form of lump ferro-molybdenum containing 80 per cent. molybdenum; it was added with the charge and no loss was allowed for.

Influence of Molybdenum

Mr. R. C. Tucker said that the first point he noted, and on which he would like a little further information, was that molybdenum was added to a chromium cast iron to eliminate the carbide streaks that penetrated into the grey background.

That was possibly quite correct under the conditions and in the series of analyses of the metal under those particular conditions, but they must remember that under some conditions molybdenum was a carbide-forming element and would increase chill. On the other hand, molybdenum was a ferrite-forming element under other conditions. It was a very delicate material to incorporate in cast iron, and they had to rely entirely from previous experience. Mr. Roxburgh had obviously hit upon the right conditions in order to correct this streakiness, but molybdenum could act in both ways. For one thing, it depended on the silicon content, but that was only one of the factors.

The hardness of the chill on the hot breaking down rolls was given as 100 Shore. They were definitely alloy rolls. He wondered whether those rolls were German, and whether the hardness was quoted from a German source, because German sources were usually 10 points higher in Shore than the corresponding tests in England. If the rolls were bought from Krupps and brought into England, they came with a certificate of 100, but when tested in English works they gave 90. He had seen paper rolls in Germany given as 90 Shore. They were beautiful rolls, but from the indices he very much doubted whether an English firm would have shown more than 80, and, as Mr. Roxburgh told them, 72 was the minimum allowed by users.

Mr. Roxburgh gave them a list of irons, all giving 1 in. chill, with varying analyses. The first one had 1.2 per cent. manganese, and about 0.9 per cent. silicon. F. J. Cook, in the "Foundry Trade Journal" about two years ago, published a Paper on actual cylinder irons for manufacturing cylinders, showing that if he kept his manganese up to his silicon content, when he machined the bore of his cylinders he invariably found a manganese-silicide glaze, which was a very harmful constituent of that metal, and that when he raised his silicon above his manganese, at least 0.4 per cent., he overcame that trouble. He would like Mr. Roxburgh's comments on that,

because these statements by different observers seemed to be rather confusing to people who perhaps had not had a lot of experience of making cylinders.

The Chill Test

It was a fact that a high total-carbon cast iron was not so sensitive to variation in chill-test technique as low-carbon material. He thought Mr. Roxburgh would be the first person to agree with him there. If they were making an ordinary engineering casting, with about 3.2 to 3.3 per cent. carbon, they had not to be so careful about quenching, but if they had a low total carbon, of 3 per cent. and under, they must definitely cool in air to a dull-red heat before they commenced to quench, and even then they must do it carefully.

Mr. Roxburgh said that in casting the chill test-piece the higher the temperature the deeper the chill. That was quite correct. On the other hand, when casting a roll he gave a series of temperatures from 1,220 to 1,270 deg. C., and mentioned that if they cast at a lower temperature they only only got an increase of $\frac{1}{16}$th chill. It was the other way round. The point was a very interesting one, and he would like a little further information on it.

The Molybdenum Question

Mr. Roxburgh, replying, said Mr. Tucker's first point was about molybdenum affecting the background in the presence of chromium. He was quite willing to admit, immediately, that, in his opinion, insufficient was known about molybdenum for anyone to be really dogmatic about its effect. He thought that much research work must be conducted on the effect of this element before they could really be satisfied about it; in fact, he had found that, to get the best results with irons containing molybdenum, for any special purpose, it had been necessary to melt the iron two or three times. He had found that molybdenum on a chilled surface of rolls did toughen the surface, but it was very difficult to

advance an explanation of why it should do so, and, on the other hand, he had found that it had an effect on the background, even without the presence of chromium.

With regard to the cold-finishing rolls which Mr. Tucker mentioned, he had actually seen those rolls, and seen the Shore's sclerescope measurement of 100, and those rolls were made in Sheffield.

Mr. Tucker raised a point with regard to some paper rolls giving a reading of 90 Shore. No doubt to-day in England rolls for paper were being made up to 75 to 80 Shore. They all knew that some Continental firms had a reputation for such rolls, but one could not get any information regarding the method of manufacture. He had an idea, though he could not substantiate it, that those particular rolls were being cast from some special furnace, such as an electrical furnace, because, when one had obtained even a similar analysis, one could not get the degree of hardness which those people claimed they could get. At the same time, he quite agreed with Mr. Tucker that oftimes they had been told about 90 Shore, and when they had actually examined and tested the rolls, they had found a difference of 10 points lower.

He was pleased Mr. Tucker had raised the interesting point with regard to cylinder iron. If he remembered rightly, Mr. Cook investigated a series of failures of cylinders, and came to the conclusion that, when the difference between the silicon and the manganese was over 0.3 per cent., then the sponginess was eliminated.

Mr. Tucker: It was a glaze, not a sponginess.

Mr. Roxburgh said that when the manganese and silicon approached similar contents, this defect became apparent. As a matter of fact, he had made cylinders containing low manganese, and he had made cylinders containing this 1.2 per cent. manganese, and he had not found any definite evidence of such a formula, if one could so term it, obtaining, so that, as far as those figures were concerned, he thought he would be

prepared to make a cylinder from similar iron to that which he had specified.

The next point raised by Mr. Tucker was very interesting—that the higher the temperature of casting of a test-piece, the deeper the chill that one obtained. The scientific explanation of that was rather difficult, and there might only be something in the fact that it was the rapid abstraction of the heat. They had got a much higher temperature in the one case than in the other, and it demanded that that heat be abstracted in the same time, and a much greater amount of heat, too.

With regard to the other point, which seemed rather contradictory—that the lower the temperature of casting of a chilled roll, the deeper the chill on the casting—he once conducted an experiment. They cast two rolls, and he purposely allowed one to be cast at a lower temperature, and they found that there was definitely an increase in chill. The only explanation which he would advance at the moment was the temperature of the inside of the roll, which involved the mass effect—the annealing back of a certain amount of the white iron due to the internal temperature. In the one case, the inside would remain hotter for a longer period than in the other, and he thought that, casting at a lower temperature, was the reason that one obtained a deeper chill on the actual casting.

Mr. Tucker said he thought the fact of a higher temperature giving a higher chill was quite easily understood from a scientific point of view, in so far as the abstraction of heat from a chilled test-piece was almost entirely by conduction, and the laws of conduction stated that more calories were abstracted per second the greater the difference in temperature. The chill was defined by the rate of cooling from a particularly narrow range of temperature, which was quite a high temperature, and with a higher casting temperature they had a much more rapid rate of cooling in the initial stages where the chill was being formed. It was only a matter of seconds, and probably only a difference in the cooling rate of 10 deg. per sec. It was a very

definite indication that that was the explanation —that the rate of cooling from the critical range, where the chill was being formed, was higher in the case of the higher-poured test-piece.

Mr. Roxburgh pointed out that when one reached into the higher temperatures, for instance, from a Sesci furnace, where temperatures in the neighbourhood of 1,500 deg. C were reached, it was very disconcerting when one cast a test-piece from such iron at that temperature, because it was white through, and it was necessary under those conditions to allow the metal to cool down in the ladle to round about, say, 1,300 deg. before one could get a measurable amount of chill.

Wheel Blanks

Mr. G. Offiler said he was interested in the chilling of wheel blanks, which Mr. Roxburgh mentioned. He should like to know if Mr. Roxburgh intended to infer that he chilled the outside diameter and also the inside diameter, so as to ensure that he had the chill running right away through the blanks. Also, what was the greatest diameter he chilled? Were they only small blanks, or were they any size? Were the wheels of the plate design, or arms? He took it Mr. Roxburgh was controlled by the Brinell hardness, to allow the machinability of the castings? He should like a little more information on that point.

Mr. Roxburgh said it was really a question of densening, and in considering densening naturally the composition and also the section of the metal was vital. The design of the wheels varied. He had cast small wheel blanks, and also larger ones. In the latter, in order to densen the surface, he had often simply used iron bricks, with some loam on, similar to a half-hard roll, just to close the grain of the metal. Supposing it was 4 in. thick, he would close up the grain of the metal for a certain distance in by strict control over the composition of the iron. One could not really dogmatise on a question like that, because there was the mass effect to be taken into consideration. If they were casting a larger wheel, it was going to remain hotter than in the case of a smaller

wheel. With a smaller wheel, that was perhaps only 2 in. thick, they would vary the thickness of the chill; they would perhaps only have a chill 1 in. thick, or 1½ in. But, as he said, they could not dogmatise. They really had to consider every particular casting, whereby they controlled their composition of metal and thickness of chill, and took into consideration also the depth of the mould, and so forth.

Air Furnace and Cupola

Mr. F. B. Ollerenshaw asked Mr. Roxburgh whether he preferred cupola melting or air-furnace melting for chilled rolls. Did he find any difference in the analysis? He did not give the composition of the chill. Also, could he tell them the life of the chill. The reason he asked for the composition of the chill was that he supposed it must be resistant, of course, but had the heat conductivity any effect on the metal poured inside the chill?

Mr. Roxburgh said, with regard to the difference between cupola-melted metal and air-furnace metal, as he stated in the Paper, the type of roll required depended on the service for which the roll was intended. If they wanted a particularly mild roll, they would want a low-carbon, low-sulphur iron, and naturally they would get that from the air furnace. On the other hand, they could make hard rolls from the air furnace by the introduction of suitable alloys. From the cupola, in most cases, they cast rolls with higher sulphur and higher carbon. It really depended on the type of roll that they desired. Naturally, in a cupola they were going to get different losses in melting from what they did in the air furnace. They had a gain in sulphur in the cupola; in the air furnace there was no increase in sulphur. In the air furnace they lost probably 0.5 per cent. of carbon, about 0.4 per cent. of silicon, and, say, 0.3 per cent. of manganese, depending upon the percentage of manganese, whereas in the cupola Mr. Ollerenshaw knew the losses as well as he did; they gained sulphur, lost silicon and manganese, and gained a little carbon.

Composition of Chills

He had found that the chills were best made from hematite—mixed with ingot-mould scrap. In some places they advocated the inclusion of 20 per cent. of steel in hematite, in order to get a closer structure, but he found that, if they went too far, the chills cracked. There was insufficient elasticity in the iron to take care of the expansion and contraction, with the result that, if they reached the extent of having a low-carbon iron, the chill would break within one or two heats. The actual structure of the metal was definitely important, but they were governed by the fact that they had got to have a high-carbon material initially to make the chill. It would not permit of a lower-carbon iron being used, and therefore that controlled to a great extent the structure of the iron. It was essential that the chills should be perfectly sound and solid, and if they cast a chill for a roll, it was always customary to put a head on the chill and machine it off. On the other hand, with small chills for densening, they ought to feed them, to ensure solidity, because it was obvious that, if there was a cavity in a chill, it was unsatisfactory.

The life of a chill involved many considerations. If they took solid rolls, for instance, probably they might get 20 or 25 castings from one chill; sometimes they might get 50. In the case of hollow rolls, where there was a smaller section of metal in contact with the chill, they would last longer. When it came to densening, one had to be very careful, because if they used a chill several times, it became oxidised; they got a film of oxide, and it should be cleaned regularly, and, really, after they had cast half-a-dozen castings, the chill should be renewed altogether, otherwise it was liable to produce blowing from the chill, etc.

Vote of Thanks

On the proposal of Mr. F. E. Steele, seconded by a visitor, Mr. Roxburgh was accorded a hearty vote of thanks.

Sheffield Branch

THE TESTING OF STEEL FOUNDRY SANDS, AND THE CONTROL OF SUPPLIES BY SPECIFICATION

By T. R. Walker, B.A. (Member)

Nowadays, the supply of most commodities to steelworks, ironworks and other industrial organisations is controlled by specifications governing the nature and standard of successive consignments, according to specifications of quality agreed upon between the seller and the purchaser. Usually, these specifications and their implications are well understood on both sides, and generally speaking there is little difficulty in supplying a commodity suitable for its intended purpose, and which has reasonably the same properties in successive consignments. Foundry sand has remained a commodity which is used in very large amounts, but scarcely ever bought or sold to specification requirements. In most cases foundries restrict themselves to buying sand from one or two particular concerns, and when ordering sand say very little beyond: "The mixture as before." A rival supplier asking for an order is usually given a sample of sand which has proved satisfactory, and asked to supply one like it, the extent of the likeness being frequently limited to visual inspection and "feel." He may have the sample analysed, and supply a sand of a similar chemical analysis, but the chemical analysis of a foundry sand is by no means the only factor in determining its behaviour in actual use in the foundry.

It is proposed first of all to describe briefly the qualities of a sand which influence its behaviour in use in the foundry, and to show that these qualities are, in the main, susceptible

to numerical evaluation. After this, suitable methods of examination of sand supplies will be briefly described, and the advantages of controlling supplies by specification will be pointed out.

Fundamental Properties

The important properties of a moulding sand include the following:—Its refractoriness, or resistance to high temperatures; its mechanical strength in the green and in the dried states; its permeability to gases; its plasticity; its grain size and its consistency in successive consignments or batches. These properties are, of course, not independent of each other.

The refractoriness of a sand depends partly on its chemical composition, and partly on its constituents. The refractory constituent is quartz, and practically all the other accessory substances have a lower fusion point than quartz, their effect on the refractoriness of the sand depending on the way in which the elements they contain are combined. For example, lime present as calcium-oxide has a high fusion point, but present as calcium-silicate fuses much more easily. The refractoriness of a sand is more important for a steel foundry than for iron or non-ferrous work, where casting temperatures are substantially lower. The sand should strip well from the castings, that is to say, it should not be burnt on to the surface of the steel or other metal. This is largely a question of the refractoriness of the sand. Burning on does not, however, depend solely on the properties of the sand. It is influenced by the size and shape of the casting, and also depends on the length of time the sand is kept at a very high temperature in contact with the metal. As steel is cast at the highest temperature of common metals, burning on of the sand is more common with steel castings than with others. A small amount of burning on, however, is not so important as is often claimed. When steel castings are annealed, as they all ought to be, the sand and scale fall off very easily at the same time. Naturally, the temperature of casting

also affects the amount of burning on, which increases as the temperature rises.

The Nature of Bond

The bond, or material which holds the sand together, consists largely of hydrated and colloidal oxides of aluminium and iron, and is present round each grain of sand. A bond due largely to iron oxide gives the sand a smooth feel, whilst a sand containing mostly an aluminium bond feels harsher and dries more rapidly on exposure to the air. On moderate heating, part of the water is driven off, but on cooling the bond may be regenerated by taking up more water. On strongly heating, however, much of the bond is for all practical purposes destroyed. In the same way, if gypsum is moderately heated, part of the water is driven off, leaving plaster of Paris, which, on cooling, will again combine with water and set hard. If, however, the gypsum is strongly heated, all the water is driven off, and the resulting material will not, on cooling, readily combine with water again. In the green state, a sand must be strong enough to be moulded; in the dried state, it must be strong enough to withstand the pressure of the steel. When dried, it must also have a hard surface, to withstand the rush of liquid metal.

A sand should be plastic, that is, it should ram easily, and stay where it is put, and it should not be resilient or springy. This is especially important where squeezing machines are being used.

The Water Content

A sand mould, even when dried, contains an appreciable amount of water. The layer of sand nearest the steel or other metal is strongly heated, and the water it contains is vaporised. One volume of water gives 1,700 volumes of steam at 100 deg. C., and this increases to about 6,000 volumes at 1,000 deg. C. Quite apart from any other gases which may be generated, it is necessary for all this steam to escape, either through the metal or through the sand. It is, therefore, very desirable that the sand should

be as permeable as possible to the passage of gases. Actually, as the steam moves into the mould from the mould surface, it meets cold sand, and much of it condenses. The permeability of the mould some distance from the face is, therefore, less important than that of the sand which is very near to the molten metal.

Troubles from Variation

It is important that successive consignments of sand should have the same properties. Small variations in the sand, which may appear unimportant to the supplier, often cause trouble in the foundry, where identical results are expected from successive supplies of sand when given precisely the same treatment. Moulders as a class are conservative, and obtain better results from a moderate sand which is uniform in its properties, than from one which varies from time to time, even though each particular consignment may be good when used in some particular way. This is simply because all consignments are treated alike, and, if they vary, the treatment which suits one lot will not give equally good results with the next. This is also important when new supplies of sand are being tried out in a foundry. The tendency is for a new sand to be given a bad name because it does not give good results when treated in exactly the same way as the sand already established.

The grain size of the sand should be as uniform as possible, to ensure good permeability. If the sand is made up of grains which are of varying sizes, the small grains fill up the spaces between the larger grains and diminish the permeability considerably. For small work, a finer grain size is permissible than for large work, as the weights concerned are smaller, the sand is at a high temperature for a shorter time, the amount of gas to be dealt with is less, and the surface of the casting better than is possible with a large grain size. For green-sand work, the grain size should be larger, as more water is present in the sand than is present in dried moulds, and, generally speaking, the larger the grain size of the sand, the greater is its permeability to gases.

Geological Formation of Moulding Sand Deposits

Natural moulding sands are largely formed by the natural denudation of the land from the decomposition of massive rocks having a quartz base. The particles are carried down rivers into the sea. When they reach the estuary or the sea, the velocity of the stream is checked, and the particles are deposited in order of size, the largest and heaviest first, and the deposit becoming finer and smaller in grain size as the distance from the land increases. Natural sands, therefore, vary along the line of deposition, not only in size of particle, but also in the amount of finely divided bonding material they contain. They also gradually thin out sideways. It is thus not surprising that when such sand beds have been raised above the sea-level by subsequent earth movements, the deposit is not uniform, and a supplier who commands a deposit of good moulding sand which is more or less uniform in reasonable quantities is fortunate indeed.

The combination in a sand of grains of a good size and shape, uniform in size, accompanied by a good type of bond in the correct amount, is not usually met with in nature, and most of the moulding sands employed in a foundry are compounded. For example, a very strong natural sand, rich in good quality bond, can be milled with silica sand (containing no bond) of a similar grain size, and these will give a compound sand of good quality and a strength which can be adjusted to suit the intended purpose. More than two sands may be mixed; for example, a sand containing a bond which is mostly aluminous may be mixed with sand with a predominant iron bond to give a compound sand with a balanced bond, this mixture then being diluted to a suitable strength with silica sand, the silica sand also serving to increase the refractoriness of the whole mixture. In all such mixtures, sands of similar grain size should be used, so as not to diminish the permeability of the whole.

TABLE I.—*Permeability of Sand Mixtures.*

Sand.	Permeability number. A.F.A. apparatus.	Green strength, lbs. per sq. in. $2\frac{1}{4}$ in. by $1\frac{1}{8}$ in. specimen.	Relative density.	Water content. Per cent.
Leighton Buzzard	501	4.0	1.67	2.5
Silica sand No. 9, with 4 per cent. Bentonite ..	501	4.0	1.67	2.5
Ryarsh silica sand with 4 per cent. Bentonite ..	50	3.25	1.47	3.8
	53	3.25	1.48	3.6
Durham milled sand	36	21.5	1.91	10.8
	38	22	1.94	9.84
Leighton Buzzard, 50 per cent.	131	18.5	1.86	6.0
Durham, 50 per cent.	131	19	1.89	6.0
Ryarsh, 50 per cent.	33	14	1.76	6.25
Durham, 50 per cent.	33	15.5	1.78	6.25

The last sentence perhaps needs a little qualification. If a medium-sized moulding sand is milled with a very coarse silica sand, the permeability of the resulting mixture will be intermediate between that of the two original sands. As a result of the mixing, therefore, the permeability of the moulding sand has been improved, whilst that of the silica sand has been diminished. If, however, the same moulding sand is milled with a fine-graded silica sand,

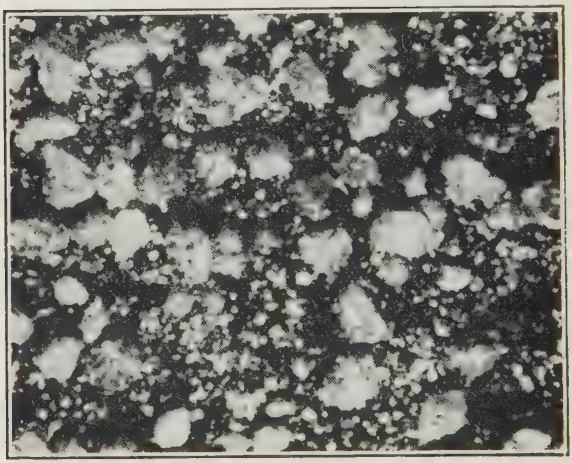


FIG. 1.—BELGIAN NATURAL MOULDING SAND. × 30.

it is possible for the permeability of the resulting mixture to be lower than that of either of its constituents. This is shown by Table I.

The shape of the sand grains and the nature of their surface are also of some importance. Spherical grains touch one another at a minimum number of points, and the more angular the grains, the more closely will they fit together, the sand becoming less open. Sand grains with a rough surface produced, for example, by partial erosion, retain a layer of bonding material

much more tenaciously than grains with a very smooth surface. Variations in grain shape and nature of surface can at present scarcely be given numerical or quantitative values, but they have their effects on the results of sand examination for other properties.

Fig. 1 shows a Belgian natural moulding sand, the grains being covered with a substantial layer

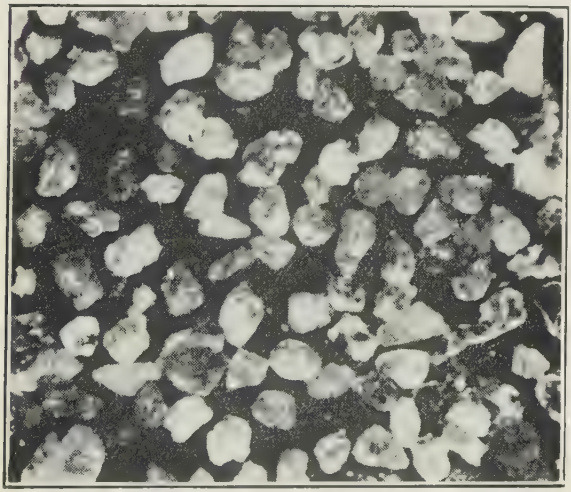


FIG. 2 SHOWS THE SAND ILLUSTRATED IN FIG. 1 AFTER REMOVAL OF THE CLAY GRADE. × 30.

of clay, and a good deal of loose clay being visible as a fine ground mass.

Fig. 2 shows the sand grains from the same sand when all the clay has been removed. The grains are remarkably uniform in size.

Moulding sands may also be made by starting with silica sand, which is highly refractory and contains no bond, and mixing this with bonding material so that each sand grain is coated with the bond. The usual bonding material used in this way is clay. This must be as refractory as

possible, so as not to interfere seriously with the refractoriness of the sand, and must be as plastic as possible, to provide the maximum amount of bond for the minimum amount of clay added, again so as not to diminish the refractoriness of the sand more than is necessary. These two requirements of refractoriness and plasticity in the clay are to some extent incompatible. Two clays commonly used in this way are ordinary fire clay and ball clay. To obtain equivalent effects as bonding material, a good deal more fire clay than ball clay is required, so that though ball clay is much more expensive than fire clay, the fact that so much less is necessary means that the effect on the refractoriness of the sand is less, and it is therefore preferable to use the more expensive clay. For reasons both of expense and refractoriness as little clay as possible is added.

Bentonite is a highly-plastic clay which has been much used for this purpose in America, and which is being employed to an increasing extent in this country. Colbond and Wilkinite are materials of a similar nature of more recent introduction. Such silica-sand-clay mixtures are prone to dry rather quickly on standing, since their bond is essentially aluminous in nature, and they have a harsh feel compared with ordinary moulding sand. On drying they tend to develop a weak face on the mould, which is easily rubbed away. They are much improved by the addition of a small amount, say $\frac{1}{2}$ per cent. of a binding material, such as wood-pulp extract, not only in the above respects, but also in green strength.

Properties of Synthetic Sand

Table II shows the result of adding different clays to the same silica sand. The chemical analyses of the clays are given, but it must be emphasised that the chemical analysis of a clay is not a reliable guide to its physical properties except in a general way. Sheffield fireclay gives the worst results. The Kingscliffe clay has not been found to be suitable for low-temperature

work of this kind, but is satisfactory for binding high-temperature refractory materials such as silica bricks.

Considering steelfoundry sands in particular, therefore, the most important factors in its good behaviour or otherwise in the foundry are its chemical analysis, refractoriness, mechanical strength and permeability. In the green state, the mechanical strength depends not only on the nature and amount of the bonding material present, but also on the water content and on the density to which the sand is rammed. The permeability to gases is also influenced by the water content and ramming density, as well as by the grain size of the sand. The water content and rammed density must therefore be included in the properties to be quantitatively determined in any complete examination of the properties of a foundry sand.

Reasons for Chaotic Supply

Provided that for a given commodity the methods of examination are universally agreed, and that consistent results can be obtained by different operators, working with similar apparatus, in widely-separated places, there is no reason why such a commodity should not be bought and sold according to precise and well-defined specifications. The fact that throughout the world there is very little buying or selling of foundry sands on a specification basis appears at first sight somewhat astonishing, in view of the very large tonnage involved. The reasons for this state of affairs are firstly that it is only during recent years that the study of foundry sands has been placed on a scientific basis, and that apparatus specially designed for sand testing has been elaborated, and secondly, that owing to the recent growth of the science of foundry-sand testing, there is no universal agreement as to the type of apparatus to be used for testing the different properties of foundry sands.

The chemical analysis of a sand can easily be carried out in any ordinary chemical laboratory.

The mechanical grading of the sand particles, *i.e.*, the division of the sand, by percentages or otherwise, into amounts of grains present whose size is between certain limits, is easily done, but even here there is no universally-accepted method of recording the results, or of carrying out the testing. At this point a division must be drawn between the examination of sands for foundry-control purposes, and their investigation from a research point of view. For the control of sand for use in the foundry, and for the examination of consignments being received, the methods employed must produce quick results with as great accuracy as can be secured in a short time. In research work, on the other hand, the methods used should be founded on accepted scientific principles, and accuracy is in this case far more important than the time taken.

Water Determination

The amount of water present as such in a sand can be determined in any laboratory in about an hour, and this method, in which the sand is heated to 105 to 110 deg. C. until there is no further loss in weight, is quite applicable to the control of consignments of foundry sands. For use in examining batches of sand actually being used in the foundry, however, especially for green-sand work, an hour is far too long a time, and the result for water content may be secured in about 5 min. by the use of the " Speedy " moisture tester, in which a known weight of sand mixed with excess of calcium carbide in a closed container evolves acetylene, the increase in internal pressure due to the evolution of the gas being read on a dial, attached to the base of the container, which is calibrated to read percentages of moisture in the sand directly.

Mechanical Testing

The mechanical strength of a moulding sand is very different in the green and in the dried states; the sand has, in fact, properties which are substantially different in the two states. When dried, it is a brittle material, resembling

TABLE II.—*Mixtures of King's Lynn Silica Sand and Clay.*

Mixture.	Permeability number. A.F.A. apparatus.	Green strength. 2 in. by 2 in. specimen, lbs. wt.	Green strength. $2\frac{1}{4}$ in. by $1\frac{1}{8}$ in. specimen, lbs. per sq. in.	Relative density.	Water content. Per cent.
95 per cent. sand with 5 per cent. Barrow clay	295	5.5	2.5	1.63	2.72
		5.5	2.75	1.64	
90 per cent. sand with 10 per cent. Barrow clay	240	16	7	1.63	4.20
		17	8	1.65	
95 per cent. sand with 5 per cent. Sheffield clay	243	1.75	0.75	1.60	1.90
		2.0	0.75	1.60	
90 per cent. sand with 10 per cent. Sheffield clay	243	3.75	1.5	1.61	2.50
		3.75	1.5	1.63	
90 per cent. sand with 10 per cent. Kingscliffe clay	191	6	2.5	1.66	2.93
		6.5	2.75	1.67	
95 per cent. sand with 5 per cent. Bentonite	321	20.5	8	1.60	2.63
		21.0	10	1.63	
95 per cent. sand with Ball clay	228	16	7	1.63	2.44
		17	8	1.65	

Chemical Analyses of Clays.

Clay.	SiO_2. Per cent.	Al_2O_3. Per cent.	Fe_2O_3. Per cent.	CaO. Per cent.	MgO. Per cent.	Loss on ignition. Per cent.
Barrow-in-Furness	60.80	25.41	2.29	0.70	1.45	4.90
Sheffield fireclay	47.00	31.28	4.72	0.20	alkalies	4.37
Kingscliffe refractory clay ..	85.40	10.20	1.00	0.30	0.80	15.60
Bentonite	60.30	23.44	3.68	1.28	Trace	3.25
Colbond	62.60	23.23	3.57	0.70	2.24	8.35
Ball clay	54.08	31.87	3.73	Trace	2.46	5.55
					Trace	10.18

in many respects concrete, while in the green state it is partly brittle and partly plastic in nature. It does not follow, therefore, that the same methods would be equally suitable for testing green and dried sands. For routine testing, whether of incoming consignments or of sand in use in the foundry, it is sufficient to test the green strength of the sand. The relation between the mechanical strength in the green and in the dried states, whilst varying appreciably with different types of sands, is yet sufficiently well known to allow the deduction to be made that, if the green strength of any given specimen of sand is satisfactory, the mechanical strength in the dried state will present no difficulties. From the control of supplies point of view, therefore, it is sufficient to determine the green strength of a sand under examination.

The mechanical strength may be determined by tensile, compressive or torsional methods, but the apparatus required, and the skill in its manipulation demanded, in the determination of the green strength of a sand in tension or torsion, preclude the use of these methods of testing for foundry control purposes. Ramming a cylindrical sand specimen and then applying pressure axially until it collapses are both easy, but in practice the results vary not only with the method of ramming, the water content, and the density to which the sand is rammed, but also with the ratio of length to diameter of the specimen. The specimen adopted by the American Foundrymen's Association is a cylinder 2 in. by 2 in., with its height equal to its diameter, whilst that recommended by the British Cast Iron Research Association is a cylinder approximately $2\frac{1}{4}$ in. by $1\frac{1}{8}$ in., the exact size being 2.256 in. by 1.128 in., with the height twice the diameter.

A.F.A. and B.C.I.R.A. Specimens

When such specimens are loaded, the resistance to compressive stresses and the resistance to shear stresses are both involved, in proportions which vary with the dimension ratio of the

test-piece. For all these reasons the standardisation of a green-strength test for sand is not an easy matter, but it is simplified if we consider only tests suitable for control purposes. The A.F.A. test-piece has the advantage that it is of precisely the same dimensions as the A.F.A. permeability test-piece, so that the same specimen may be used for testing both permeability and green crushing strength. Another advantage is that the specimen is subjected to three

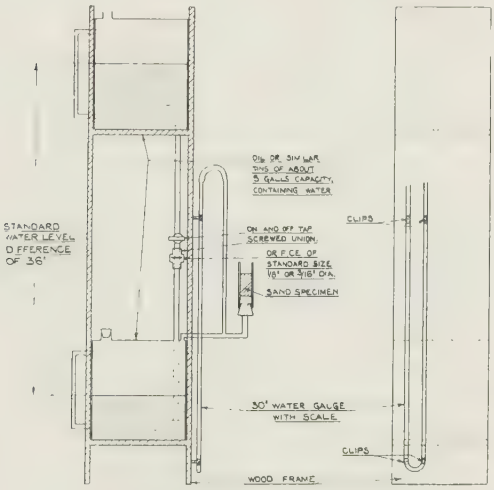

STANDARD WATER LEVEL DIFFERENCE OF 36'
ON AND OFF TAP SCREWED UNION
OR P.C.E. OF STANDARD SIZE 1/8' OR 3/16' DIA.
SAND SPECIMEN
CLIPS
30' WATER GAUGE WITH SCALE
CLIPS
WOOD FRAME

FIG. 3.—SAND PERMEABILITY APPARATUS (AS MODIFIED BY RICHARDSON AND OTHERS).

blows from a standard ram, so that the method of ramming is the same for all specimens, provided that the standard A.F.A. apparatus is used. The B.C.I.R.A. specimen has the advantage that it is probably a more scientifically designed test-piece, in that the dimension ratio between length and diameter of 2:1 probably gives results which are a truer reflection of the properties which are important in the foundry than the A.F.A. specimen, with its dimension

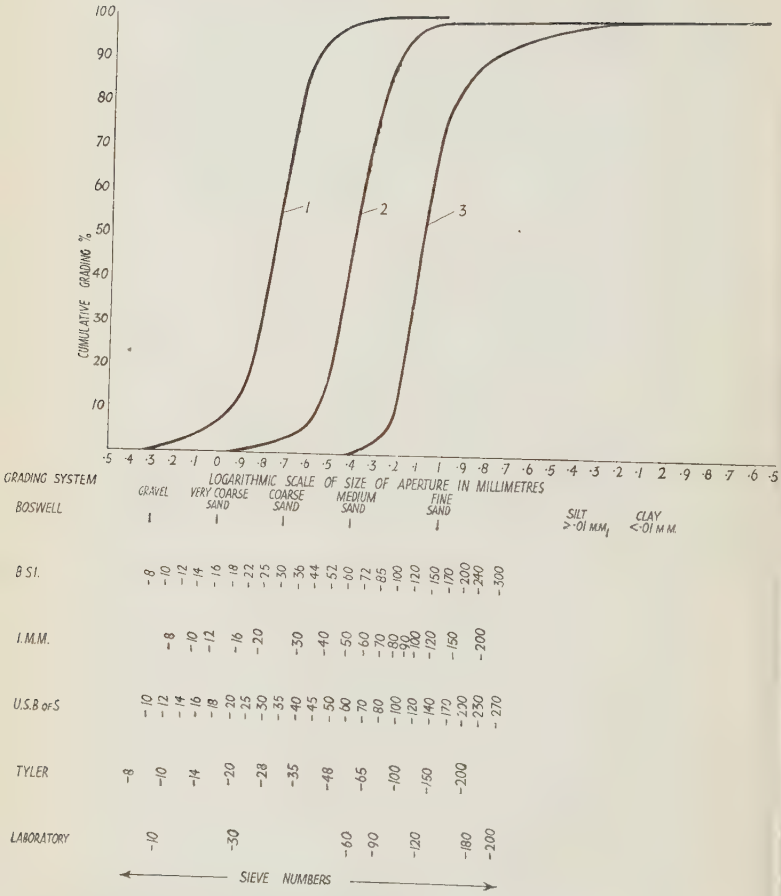


FIG. 4.—COMPARISON OF SIEVE NUMBERS SHOWN NUMERICALLY AND GRAPHICALLY.

ratio of 1:1. A further advantage is that the B.C.I.R.A. specimen may be compressed in several different ways to give any desired degree of ramming, *i.e.*, to give different apparent densities for different specimens. These two points are important where research work in sands is concerned, but are of no particular moment for control purposes. Any specimen may, however, be rammed by hand to a particular relative density without the use of the special rammer designed by the A.F.A.

For control purposes, either specimen may be used, and it may be compressed by the A.F.A. standard rammer, or to a particular apparent density by some other method. In either case the method of applying the compressive load is the same; the specimen is merely put on the platform of a spring weighing balance, such as is used for parcels, and the load is applied by a screw held in a frame, the load required to make the specimen collapse being read directly on a dial attached to the weighing balance. A suitable frame containing the screw by which the load is applied has been designed by the B.C.I.R.A., and may be very easily purchased at a low figure.

The permeability of a sand to gases is naturally best determined by timing the passage of a given volume of gas at a given pressure through a test specimen of the sand. In the apparatus designed by the A.F.A. the permeability specimen is a cylinder 2 in. by 2 in. This is given three blows with a standard ram, and then the time is taken for 2 litres of air to pass through the specimen at a known pressure, which is applied by a small head of water. The figure given may be left in seconds, or alternatively it may be converted into a permeability number. This number is calculated from the following equation.

$$\text{Permeability number} = \frac{\text{No. of c.c. of air} \times \text{height of specm'n in cm.}}{\text{Area of specm'n in sq. cm.} \times \text{pressure in gm. weight} \times \text{min.}}$$

In the case of the A.F.A. apparatus this may be reduced to the following:—

$$\text{Permeability number} = \frac{30072}{\text{Pressure in gm. weight} \times \text{time in sec.}}$$

In an apparatus designed by the B.C.I.R.A. the specimen is a cylinder 20 cm. long with a cross-sectional area of 40 sq. cm., and coal gas is passed through the specimen at a pressure of 7 cm. of water until it ignites at the other end,

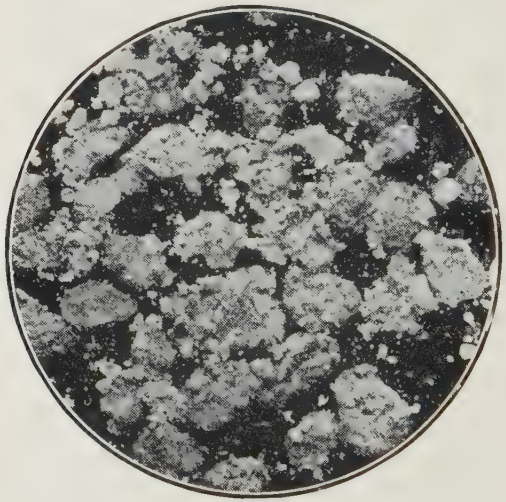


Fig. 5.—Facing Sand as Received. × 30.

the time occupied in this passage being noted. In this apparatus the specimen is rammed by hand to any desired limit of density. This piece of apparatus, while very useful for research work, is neither so quick nor so handy as the A.F.A. apparatus, which is consequently preferable for control purposes.

The Richardson Apparatus

It is possible to use the principle involved in the A.F.A. permeability apparatus, without

actually using the standard apparatus, which is somewhat expensive. An equivalent apparatus for control purposes, suggested by Mr. R. J. Richardson, can easily be constructed from two large tins, say 5-gallon oil tins, the upper one of which contains water and is connected to the bottom one by means of a pipe, so that air can be pushed out of the bottom tin, by the ingress of the water, through the specimen of sand, the time necessary for a given volume of air to

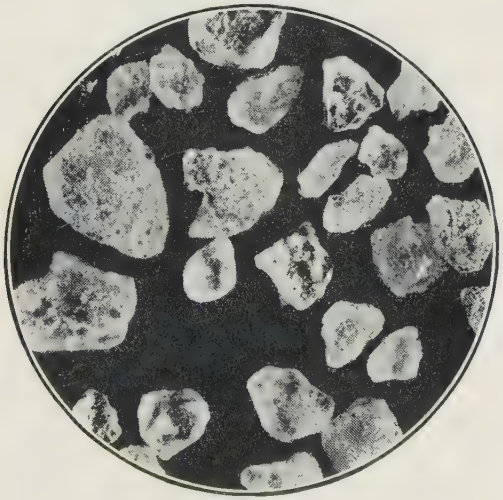


Fig. 6.—Facing Sand after Removal of the Clay Content. × 30.

pass through the sand being again noted. This apparatus, which is illustrated in Fig. 3, can be constructed very cheaply, and gives sufficiently accurate results for control purposes. With both the A.F.A. apparatus and that illustrated, the back pressure set up by the resistance of the sand to the passage of air through it may be measured in terms of a column of water, and this is a quicker method of working, though probably less accurate than actually timing the

passage of, say, 2 litres through a sand specimen. With the apparatus illustrated, the permeability specimen employed may be either the A.F.A. 2-in. by 2-in. specimen or the B.C.I.R.A. $2\frac{1}{4}$-in. by $1\frac{1}{8}$-in. specimen. Which is employed is a matter of indifference, so long as it is distinctly stated in the record of the results. These specimens are the same as those used for determining the green crushing strength.

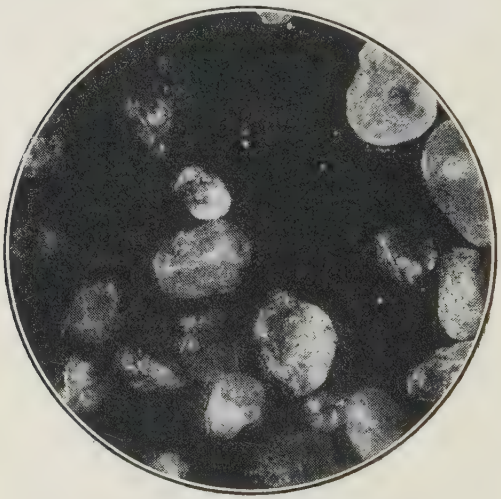


Fig. 7.—Silica Sand Fulfilling the Requirements of a Steel Foundry. × 30.

Provided that the air is able to flow through the orifice much more quickly than it can escape through the sand specimen; in other words, provided that the orifice is of sufficiently large diameter, it is possible from the observed results of time taken and water pressure obtained using the apparatus illustrated in Fig. 3, to calculate the permeability number in exactly the same way as is done with the A.F.A. apparatus. The two

numbers correspond, and the same sand examined on both types of apparatus ought to give the same permeability number. A detailed account of the method of using this modified permeability apparatus is given in Appendix B of the Paper entitled: "Routine Methods of Testing Green Sands," which appears in the "Proceedings of the Institute of British Foundrymen" for 1932/33.

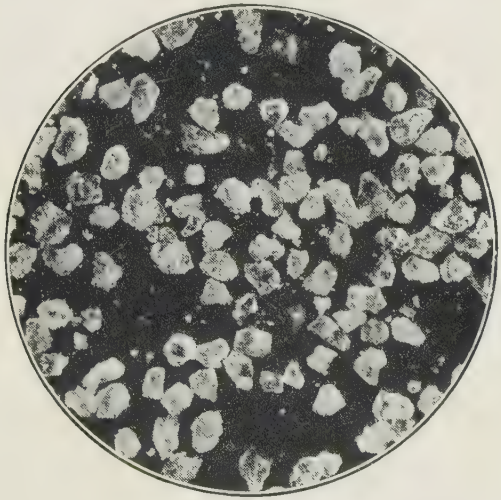


FIG. 8.—FINE-GRAINED SILICA SAND SUITABLE FOR SMALL CORE WORK. × 30.

If the results of permeability determinations are to be compared with those obtained by some other workers, it is best to express the permeability in terms of the permeability number, which is derivable from the results obtained with either the A.F.A. or the modified permeability apparatus. If, however, the results are to be used purely for control purposes in the foundry, and for comparison of successive

batches or from day to day, it is easier to use the number of seconds with the A.F.A. apparatus, and the height of the water column in inches with the modified apparatus.

Sieving Tests

The division of the sand mechanically into particles of different sizes may be carried out completely by sieving. It is far better, however, to remove the fine particles which comprise the clay and the silt by means of elutriators, in which the sand is placed in a glass cylinder, through which an ascending stream of water is flowing sufficiently rapidly to carry away the small particles, while leaving the large particles behind. The mesh sizes of the sieves used have not been standardised, but the division of particle size frequently adopted in this country for research work may be conveniently applied to foundry and supply control purposes. These sizes and their designations are as follow:—

Gravel ..	.. Above 2 mm. dia.					
Very coarse sand	Between	1	and	2	mm.	dia.
Coarse sand ..	,,	0.5	,,	1	,,	,,
Medium sand ..	,,	0.25	,,	0.5	,,	,,
Fine sand ..	,,	0.1	,,	0.25	,,	,,
Silt	,,	0.01	,,	0.1	,,	,,
Clay ..	.. Less than 0.01 mm. dia.					

As already indicated, the clay in a moulding sand occurs largely as a coating surrounding each grain of sand, and to loosen this clay such a sand is boiled for about 10 min. in a solution of ammonia of about 2 per cent. concentration. After this, the grading is carried out by means of sieves with meshes of the appropriate sizes, down to the size of grain designated fine sand, while the silt and clay are removed in elutriators having two different rates of flow, the silt and clay being estimated by the weight carried off in each case by the stream of water.

It is unfortunate that so many different systems of particle classification are employed, since this makes it very difficult to compare the results obtained by different workers. A comparison of different systems is shown in Fig. 4.

The horizontal scale is a logarithmic millimetre scale, and the sieve numbers or designations are located according to the width of aperture. It will be noticed that in some cases there is a considerable difference in the positions occupied by corresponding sieve numbers. The laboratory sieves referred to are sieves purchased in the ordinary way, and may vary considerably in size of opening, since the number of the sieve refers only to the number of holes, without the

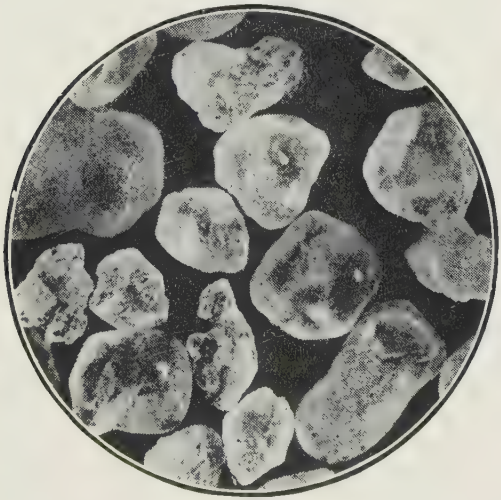


FIG. 9.—COARSE-GRAINED SILICA SAND FOR GREEN SAND MOULDING WHERE IT IS PROPOSED TO MIX WITH BONDING MATERIAL. × 30.

diameter of the wire forming the sieve being specified. Since the issue of the new B.S.I. specification for sieves, the I.M.M. have discontinued the use of their sieves as standards, but they are still being used fairly extensively. Other systems of sieving are also employed; for example, Girardet, in an article appearing in the "Bulletin de l'Association Technique de Fonderie" for July this year, used the following:—

Grade 1 ..	Less than 2 mm.	Greater than 1 mm.
„ 2 ..	„ 1 „	„ 0.5 „
„ 3 ..	„ 0.5 „	„ 0.25 „
„ 4 ..	„ 0.25 „	„ 0.125 „
„ 5 ..	„ 0.125 „	„ 0.1 „
„ 6 ..	„ 0.1 „	„ 0.05 „
„ 7 ..	„ 0.05 „	„ 0.01 „
„ 8 ..	Bond material.	

whilst Seger's original classification of grain sizes is as follows:—

Coarse sand	Greater than 0.33 mm.	
Fine sand	Less than 0.33 mm.	Greater than 0.04mm.
Silt ..	„ 0.04 „	„ 0.025 „
Rock dust	„ 0.025 „	„ 0.01 „
Clay ..	„ 0.01 „	

The vertical ordinate indicates percentages which are cumulative, that is to say, the percentages of the different sized particles are progressively added, beginning with the largest sized particles, so that for any given size of aperture the percentage indicated is that of all particles greater than that size. If a sand consisted of particles all of the same size, the graph would be merely a straight vertical line drawn upwards from the appropriate particle size, so that the more nearly the graph for a given sand approaches the vertical line, the more uniform is the grain size of the sand. Curves for three silica sands are shown on the graph.

No. 1 is a coarse silica sand and is Leighton Buzzard Sand No. 9.

No. 2 is a medium-sized silica sand from Chelford.

No. 3 is a fine-grained Ryarsh silica sand.

This method of plotting results is of value, since the results of different workers using different sizes of standard sieves can be plotted on the same graph and compared.

Media for Control

For control of foundry-sand supplies, therefore, the methods of test and the apparatus required are as follow:—

(1) *Chemical analysis* (including water content).—This can be carried out in any ordinary

chemical laboratory and calls for no further comment.

(2) *Mechanical grading.*—This is carried out with sieves of the sizes mentioned above, and with two elutriators for silt and clay respectively, and presents no particular difficulty.

(3) *Mechanical strength in the green state.*—Where a firm, whether a sand supplier or a sand user, is in possession of the A.F.A. standard permeability apparatus, this may conveniently be used to ram the specimen for determining the green compressive strength. Where this apparatus is not available, specimens in the form of cylinders either 2 in. by 2 in., or $2\frac{1}{4}$ in. long by $1\frac{1}{8}$ in. dia., may be rammed by hand. In every case it is necessary to state the rammed density, and to give the water content. Whichever specimen is used, it is crushed on the pan of a spring parcels balance, as already described.

(4) *Permeability.*—Again, where the A.F.A. standard apparatus is available, this is quite convenient to use. Firms not in possession of this apparatus, and not wishing to buy it on account of its high price, can use the apparatus illustrated in Fig. 3. This may be made up by the firm themselves, or it may be purchased complete from one or two firms specialising in such apparatus. The report of the test should indicate which apparatus has been used. It should also state the size of the test specimen and give the number of seconds required for two litres of air to pass through the specimen, together with the permeability number. With each type of apparatus there is provision for the use of a standard orifice. If this is utilised in the testing of the sand the result is given as a pressure of water, which in the case of the A.F.A. apparatus is in centimetres and in that illustrated is in inches of water. A sand laboratory thus includes apparatus for permeability by the A.F.A., B.C.I.R.A., and Richardson's apparatus, green crushing strength for both A.F.A. and B.C.I.R.A. specimens, and elutriators, all of which can be very compactly arranged. There

is no need to suppose that a laboratory for testing sand occupies a very large space or that it costs a tremendous amount of money.

Typical Specifications

The sands purchased by a foundry may be roughly divided into three classes:—(1) Facing sand, already mixed and prepared, and supplied ready for use; (2) silica sand, which is used as

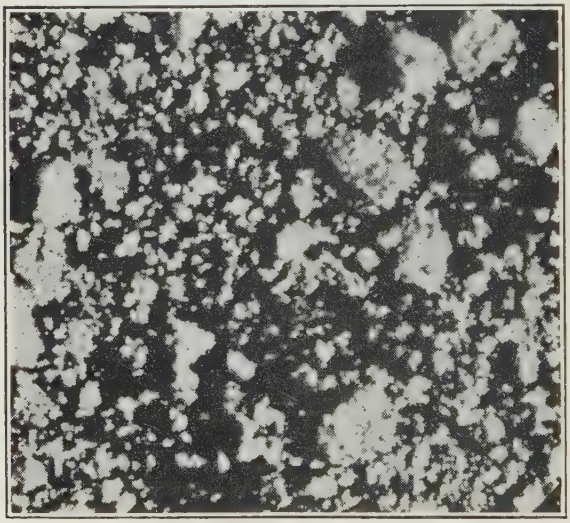


FIG. 10.—STRONG RAW MOULDING SAND WHICH REQUIRES MILLING BEFORE USE. × 30.

such, bonded with oil or other core compound for the production of cores, and is also mixed (*a*) with the above facing sand to reduce its strength where this is considered necessary, and (*b*) with strong raw moulding sand which goes into the foundry unmilled (this must be milled and diluted with silica sand to form moulding or facing sand of the strength required for its intended purpose); and (3) strong raw moulding

sand, either milled or unmilled, and unfit for use as received.

Facing or Moulding Sand Ready for Use

For a typical steel foundry, making moderate-sized castings of a minimum weight of, say, 14 lbs. or so, a sand complying with the following specification would give satisfactory results.

Chemical Analysis.—SiO_2, 89 to 92 per cent.;

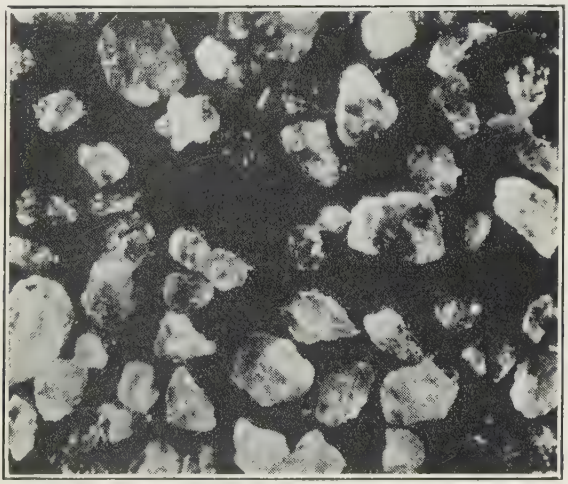


Fig. 11 shows the Sand Illustrated in Fig. 10 after Washing. × 30.

Al_2O_3, 4 to 6; Fe_2O_3, 1.5 to 4.0; CaO, 0.2 max.; and MgO, 0.2 per cent. max.

Mechanical Grading.

Coarse sand ...	5 per cent. max.
Medium sand ...	30 to 40
Fine sand ...	45 to 35
Silt	7 max.
Clay	12 to 16
Total sand grade	**75 to 80 per cent.**

Green Crushing Strength.—7 lbs. per sq. in. minimum, with a water content of 7.5 to 8.5 per cent., and at a relative density of between 1.8 and 2.0 gm./c.c.

Permeability.—In the A.F.A. apparatus, not more than 70 sec. for the passage of two litres of air, the water content being 7.5 to 8.5 per cent. The corresponding permeability number is 43, and this may be calculated equally well from results with the modified permeability apparatus.

In such a specification, the refractoriness of the sand is safeguarded by the silica specification, whilst the type and amount of bond are determined by the alumina and ferric-oxide in the chemical analysis, and by the clay content in the mechanical grading. The amount of silt is limited, as this contains only a small amount of bond, and is made up largely of very small sand grains which diminish the permeability. The size of the sand grains specified gives a reasonably open permeable sand, which, if properly used, will give no trouble in the foundry.

Fig. 5 illustrates a facing sand which is supplied ready for use, in the as-received condition. The grains are well covered with a layer of clay, and there is a certain amount of loose clay scattered in the background.

Fig. 6 shows the sand grains from the same sand after removal of all the clay. This sand would comply with the specification laid down above.

Silica Sands

(1) *Medium.* For use in a steel foundry, a silica sand to the following specification would be quite suitable.

Chemical Analysis—

Silica	97 per cent. min.

Mechanical Grading—

Coarse sand ...	8 per cent. max.
Medium sand ...	50 to 65.
Fine sand ...	45 to 30.
Silt plus clay ...	4 max.
Total sand grade	96 per cent. min.

Mechanical Strength (Permeability).—As this sand contains no bonding material it has no mechanical strength, and cannot be formed into a cylinder which is self supporting. The permeability is sufficiently covered by the specification of mechanical grading. These remarks apply also to the two silica sands which follow.

Such a sand as this is very suitable for all kinds of core work met with in a steel foundry making moderate sized castings. It may also be used for mixing with the prepared moulding sand described above, when a mixed sand of lower strength is required. It is slightly coarser in structure than the moulding sand, and will therefore give a mixture somewhat more open and permeable than the ready-mixed moulding sand, and will give a weaker facing sand which will prove quite satisfactory in service in cases where weaker facing sand may be used.

Fig. 7 illustrates a silica sand which would comply with the above specification. It is reasonably uniform in grain size, and some of the grain surfaces are rather rough, thus enabling a thin layer of binding material to attach itself more firmly to the grain surfaces than if the grains were perfectly smooth.

(2) *Fine.* For small core work and small castings weighing a few ounces or a pound or two, where the quality of the surface is of importance, a sand complying with the following specification is suitable. For both cores and moulds it is mixed with a core compound and dried in the core oven.

Chemical Analysis—

Silica	97 per cent. min.

Mechanical Grading—

Free from gravel and coarse sand	
Medium sand ...	1 per cent. max.
Fine sand ...	75 to 85.
Silt and clay ...	25 to 15.

Fig. 8 illustrates a fine-grained silica sand which would comply with the above specification, and which is frequently used for the purposes mentioned. In both this and the previous sand the "clay" is not actual clay, but consists simply of very small particles of silica. An actual content of clay, except in very small amounts, is guarded against by the chemical analysis specification of 97 per cent. silica as a minimum.

(3) *Coarse.* For green sand work, a very permeable silica sand is sometimes mixed with fire clay, ball clay, or Bentonite to give a

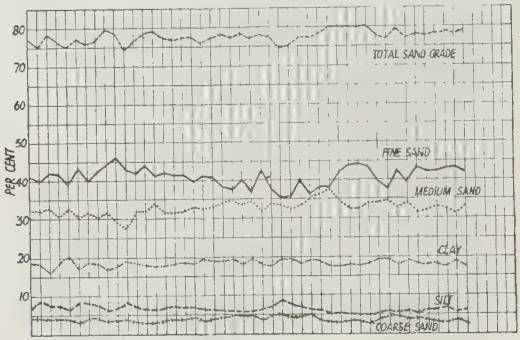


FIG. 12.—GRADING OF A FACING SAND AS SHOWING BY SAMPLES FROM SUCCESSIVE CONSIGNMENTS.

highly permeable facing sand, in order to avoid scabs and blow-holes in the castings. A suitable specification for silica sand of this nature is as follows:—

Chemical Analysis—

Silica	97 per cent. min.

Mechanical Grading—

Gravel	8 per cent. max.
Very coarse sand	2 per cent. max.
Coarse sand ...	50 to 60.
Medium sand ...	40 to 30.
Fine sand ...	3 max.
Silt plus clay ...	1 per cent. max.

Fig. 9 illustrates a coarse-grained silica sand of this type which would comply with the above specification.

Of the two sands last considered, the first one will have as high a permeability as is reasonably possible for a sand of such a fine grain, and is suggested for small work only. The second sand, with its very large grain size, provides a very permeable green sand which is suitable for any heavy casting up to the largest which can be made in green sand, but which is not suitable for very small work, as the surface of the castings

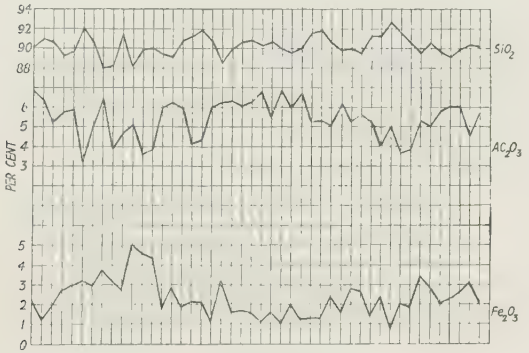


Fig. 13.—Chemical Grading of a Facing Sand as shown by Successive Deliveries.

is rougher than the surface demanded in small work.

Strong Raw Moulding Sands

Sands of this nature come into the foundry unmilled, in that state possessing little bond, or milled, when they become very strong, being unfit for use as received. They are used as raw material from which facing or moulding sands of different strengths may be produced, by mixing them with silica sand. The amount of silica sand which must be added to produce a moulding sand with particular properties naturally depends on the amount of bonding material

present in the raw moulding sand. It is possible, therefore, to have a series of such sands of varying constitution which would all give satisfactory service in the foundry when mixed with different amounts of silica sand to the same amount of raw moulding sand, for a resulting mixture having approximately the same properties in each case. Here, therefore, assuming that the actual grain size of the sand grains is satisfactory, the value of the sand to a foundry depends largely on the clay content and to a less degree on the silt content, as the amount of clay present is the chief factor in determining how much the raw sand can be diluted with the cheaper silica sand. One suitable specification for such a sand would be as follows:—

Chemical Analysis.—Silica, 85 to 88 per cent.; Al_2O_3, 5 to 9; Fe_2O_3, 3.5 to 5.5; CaO, 0.4 max.; and MgO, 0.4 per cent. max.

Mechanical Grading.

Very coarse and coarse sand ...	10 per cent. max.
Medium sand ...	20 to 35
Fine sand ...	45 to 30
Silt	15 max.
Clay	20 to 25
Total sand grade	65 to 75 per cent.

Green Crushing Strength.—12 lbs. per sq. in. minimum for a relative density of 1.9 gm. per c.c., and 15 lbs. per sq. in. minimum for a relative density of 2 gm. per c.c., with the water content at its optimum value.

Permeability.—With the A.F.A. apparatus not more than 120 sec. for the passage of 2 litres of air, the water content being the same as in the previous test. The permeability number corresponding is 25, and this may be obtained equally well from the modified permeability apparatus.

Before such a sand can be tested in the above way it must be milled, unless it has been milled before delivery. This may be done by hand, in a mortar, or more conveniently and better in a

small hand mill. The reason for quoting no definite figure for the water content is that these sands develop their maximum strength at water contents which may be substantially different with different sands, according to the type of bond, high-alumina bonded sands requiring more water than high-iron-oxide bonded sands. A definite figure for water content could, however, easily be fixed for any particular bed of strong moulding sand.

An alternative method of controlling the supply of such a sand would be to demand that a given amount of it, milled up with a specified amount of a silica sand of a particular grain distribution, would give a facing or moulding mixture having the properties indicated in the specification already described for facing or moulding sand ready for use.

Fig. 10 illustrates a strong moulding sand which would comply with the above specification. The grains are covered with clay and there is much additional clay loose and available for coating the surface of other grains. Fig. 11 illustrates the silica grains of the same sand which have been washed free from clay. They are reasonably uniform in size.

The above specifications are by no means exhaustive, as it is quite possible to use other sands with different properties in a steel foundry, but they represent typical sands which are extensively used in this country, and a steel foundry could make good castings if it were supplied with no other sands than those specified. The specifications are not difficult to meet, and there are many sand-supplying firms in this country which would have no difficulty in supplying sands to comply with the specifications. In actual fact, the specifications do not cover every one of the properties which influence the behaviour of sand in a foundry, but the addition of other tests covering other properties could be made when sufficient experience had been gained in purchasing sands to the requirements of the specifications already outlined.

Results of Testing Consignments of Sand

Following on the above account of suggested sand specifications, it is now proposed to show how in some cases the properties of successive consignments of ostensibly the same sand vary. Fig. 12 shows the mechanical grading of a facing sand which is supplied to foundries ready for use, and indicates the distribution of grain size in 46 successive consignments of the same sand from the same supplier. It will be noticed that all the consignments give very similar results,

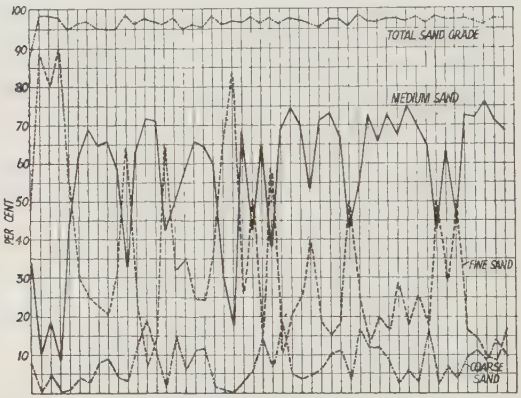


FIG. 14 SHOWS THE RESULTS OF GRADING FIFTY SUCCESSIVE DELIVERIES OF SILICA SAND.

and that the sand is reasonably uniform throughout the whole period. Fig. 13 shows the chemical analysis of the same sand as determined from the same consignments. The analysis is not quite so uniform as the grading, but it is still reasonably satisfactory. It will also be observed that nearly all the consignments would comply with the specification already laid down for such a sand.

Fig. 14 illustrates the mechanical grading of 50 successive consignments of a silica sand, all from the same supplier, and all supposed to be

of the same sand. In this case it will be observed that successive consignments vary widely in the distribution of grain size. These differences caused considerable difficulties in the foundry, as sand of such varying properties could scarcely be expected to behave in a uniform manner when successive supplies were treated in the same way.

Fig. 15 shows the results of examination for mechanical grading of 20 successive more recent consignments of the same sand as Fig. 14. Here it will be observed that the consignments are very much more uniform in their properties. Apart from two unfortunate lapses, nearly all

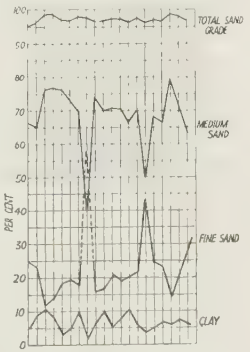


Fig. 15 shows the more recent Variation of Twenty Deliveries of Silica Sand.

these consignments would comply with the specification already described for such a sand. This considerable improvement is due very largely to the fact that the supplying firm were notified that every consignment was being examined, and were given information regarding results of the examination for their guidance. With nearly all of the sand covered by Fig. 15, no difficulty would be experienced in a foundry if different consignments were treated in the foundry in exactly the same way.

Advantages of Specifications for Foundry

There is no doubt that if the control of supplies of foundry sand were in the main covered

by specifications, the system would be a great improvement on that now in vogue, and would be advantageous to everybody concerned.

To the foundries, such a system would ensure supplies of sand of known properties, and in addition would means that successive consignments could be relied upon to give just the same results when treated in the same way each time. This would be a great help, and if the sand were really uniform, it would dispose of a good many excuses for bad work. In the case of supplying firms wishing to supply trial sands, it would be easier for the foundry management to say either: "This is the specification to which our sand is supplied, send some to comply with it," or "These are the properties which we should like a sand to possess. Can you supply such a sand?" In addition to this, if the properties of different kinds of sands were well known throughout the trade, so that any foundry could detail the properties of the sands which it used or desired to use, this would promote a healthy spirit of competition between suppliers of foundry sands, who would have a good idea beforehand of the type of sand to supply to a foundry, instead of as at present supplying a foundry with a sand which the supplying firm knows has given good results in one foundry, and therefore believes ought to be equally suitable for another foundry.

To the sand seller supplying to specification would be an assurance beforehand that a foundry would be satisfied with the sand it received. Examination of its own sand to ensure that it complied with the specification would also give an early warning to the selling firm when the character of its sand, as excavated or otherwise obtained, began to change. It would also be easy to quote for a supply of sand to fresh foundries if the specifications required for such sands were well established.

A further advantage to the supplying firm would be that by testing its own sands according to established methods it would soon obtain a knowledge, expressed quantitatively, of the

various properties of the sands obtained by mixing sands of different kinds in specified proportions, and this would make it very easy to supply ready-mixed sands with slightly different properties to suit the requirements of individual foundries.

In short, the establishment of routine sand testing by agreed methods and the control of foundry sands by specification would not only enlarge the knowledge of those engaged in the foundry industry and in the refractories industry regarding the properties of sands of all kinds, but would also be of considerable benefit to the industries concerned, as it would put the purchasing and using of sands on a far sounder and much more satisfactory basis than the trial and error system which has been so common hitherto.

DISCUSSION

Mr. N. R. Ridsdale, after conveying greetings from the Middlesbrough Branch, referred to the questionnaire that had been sent out by the Sands Sub-Committee. One of the objects in forming the organisation was to encourage founders to make contact with each other. Great benefit was to be derived from the co-operative study of foundry problems. A questionnaire was often liable to be regarded with suspicion at first, but he hoped that this questionnaire would be accepted in the spirit in which it was evolved and would really be found useful to foundrymen in different parts of the country. They had therefore arranged for the questionnaire to be issued through the different branches. It was hoped in that way to get useful information from all over the country in the course of the present session.

Necessity for Familiarisation with Figures

The sand tests would enable founders to grasp what the different figures meant. Until they had had some contact with the tests a permeability number of, say, 50 did not mean very much to them, but when they had really associated it

with a certain sand with which they were familiar it would have some definite notion, and they would begin to see how the tests were valuable. They had already heard from Mr. Walker the standard tests which the Sub-Committee had recommended for acceptance throughout the country and, of course, he had already made it clear that those standard tests and standard equipment applied to *routine* tests. He was not sure if Mr. Walker had made it quite so clear that the idea of the tests was that they could be used in any foundry. They were simple, easily-made tests which could be applied by an apprentice moulder, or anyone else who was not provided with a chemical laboratory. He was sure that the feeling was shared by all that they wanted to get interested in the subject of sand testing, and any mere discussion as to precise dimensions of test-pieces, or precise details of apparatus, was relatively a secondary matter. There were sure to be members who would feel that for special purposes and researches they would need to use different or additional methods of testing sands. Moreover, some people would have their own ideas about apparatus and methods of routine testing, but the main object was to get simple standard tests which could answer for all ordinary purposes. To his knowledge, during the last year or two, 25 to 30 firms in the country were equipped with the standard apparatus recommended by the Sub-Committee. They were using it regularly, and, he believed, they were quite satisfied with it. At the present time the Sub-Committee was largely engaged in dealing with tests and queries arising out of the questionnaire, but they were also dealing with the subject of dry-sand and core-sand tests in addition to green-sand work. They were also dealing with the question of mould-hardness testing. Those things were keeping their hands fairly full at present. He hoped that the questionnaire would be made use of in the Sheffield Branch and that the founders would come forward and supply the necessary samples for Mr. Walker to make the tests.

Skin of Casting the First Consideration

Dr. J. G. A. Skerl, referring to the lecturer's remarks on permeability, stated that according to the modern trend of thought permeability should be subordinated to the claims of a better finish on castings. In American practice, especially with regard to synthetic sands, the addition of a fine grained material like silica flour had been advocated in order to improve the finish on castings. The addition of the silica flour to the facing sand definitely lowered its permeability, but nevertheless the surface of the castings was improved. Care was taken, however, that the backing sand had a permeability greater than the facing sand and therefore did not contain the silica flour.

The percentage of bonding material or clay in a moulding sand had some influence on the refractoriness of the material, but it was not so great as generally imagined, especially nowadays when the tendency was to use less heavily bonded facing sands due to more efficient sand treatment plants and the greater use of moulding machines.

Ramming Densities

The lecturer in his short survey of testing methods had omitted one which was of the greatest importance, especially in its practical implications. The American methods of testing sand at one particular ramming density, by dropping a weight three times on a sample of sand (greater or less number of blows yielding an unevenly rammed test-piece), was suitable for purely routine testing, but ignored the fact that one of the secrets of the moulder's art was the necessary variation in ramming for different jobs in different sands in different foundries. The sand should be tested as far as possible in the condition as it is used on a particular job, and the variable which was most important was the degree to which the sand had been rammed. The method, known as the double-compression method of preparing a test core to any suitable degree of ramming, brought

forward by Mr. W. J. Buchanan, one of the members of the I.B.F. Sands Committee, was most important, and had been adopted by the British Cast Iron Research Association (Special Report No. 2, 1934), and allowed the use of the same core for both strength and permeability testing.

Specifications May Create Difficulties

The question of specifications for moulding sands was one upon which a cautious attitude should be adopted, since published data from one particular foundry in an area may be misleading to other foundries in other districts, using the same or different sands, or using different methods of moulding. Full disclosure of all the details of the sands and their methods of use was essential if full benefit is to result from the publication or study of such data. The results given by Mr. Walker yielded green strength data, but of great importance to the steel founder was the strength at higher temperatures in view of the great cutting action of molten steel. Unfortunately there was no definite relation between the green and dried strength of a moulding sand, and this relation was a vital property of each sand.

Local Considerations

The author's figures would doubtless be tried out by other steel founders all over the country. Difficulty would arise since the figures were based on certain sands which were probably the cheapest in Sheffield, but which would be much dearer in other districts. The sands used in the other districts would have different properties, but they give satisfactory results in the form of moulds. The position was that many more Papers by steel founders on the properties of their moulding sands were required, and only then will it be possible to give adequate specifications containing upper and lower limits for the properties of different sand for different jobs under varying conditions. The present Paper only gave certain specifications for certain conditions, but was a start in the right direction.

Mr. Ridsdale had remarked that there were over 25 sets of A.F.A. sand testing equipment in this country. There were approximately 100 sets of the B.C.I.R.A. sand testing apparatus spread over this country and abroad which could be used for testing the sand according to the methods advocated by the B.C.I.R.A., and could be adapted for testing the A.F.A. test-pieces. The B.C.I.R.A. were co-operating with the I.B.F. Sands Committee, and he hoped that the questionnaire which had been prepared would be universally answered.

Worth of Various Tests

Mr. Walker, replying to Dr. Skerl, said he quite agreed that it was a common practice, not only in America, but also in England, to treat the surface of the mould with white or black silica paint, which certainly gave a thin superficial layer of very low permeability. In some cases this appeared to improve the surface of the casting, but in other cases it did not appear to have any particular effect. He did not think he had omitted the consideration of ramming density in his Paper. He had also referred to the fact that the B.C.I.R.A. apparatus allowed a specimen to be made of any desired density. It was also possible, when using the A.F.A. specimen, to ram to any density, if the standard ramming apparatus were not used. He agreed that ramming density was important, and must be stated in the record of the test, otherwise the test was useless. He did not specifically mention the double compression method in his Paper, but agreed that it was a good method; there were also other good methods in use, which were described in detail in the report of the Sands and Refractories Sub-Committee referred to in the Paper.

The Time Factor

With regard to the specifications outlined in the Paper, he agreed that it was probable that they would not be of general application in their present state, but he thought it was time they

began thinking about specifications so that in time some could be made that would be of general application. If they never started, they would never get anywhere. It was true that other foundries used different sands from those in the foundries with which he was connected, but some of the sands referred to in the Paper were used all over this country, and many of the sands used in different parts of the country had very similar properties. He had actually tested from this point of view sands from England, France, Belgium, America and Australia, and it was surprising to find how generally similar many of them were, and how closely they could be made to give similar mixtures by modifications in the method of treatment. He agreed that the specifications were by no means exhaustive, and this was stated in the Paper. They were simply typical specifications of selected sands, and it was hoped that by future efforts they would be elaborated and made of general application.

Hardness Tests

Mr. Ridsdale said he had found the mould hardness test to be of considerable value, particularly in regard to mechanically-squeezed or prepared moulds. Thus, if they rammed a hand specimen, they might find a mould hardness of 70, but in the case of a hydraulically-squeezed mould, they might find it to be, say, 50. Of course, they did not know what the relationship was between one and another.

Control of Natural Sands

Mr. J. Roxburgh said that the knowledge gained by the carrying out of the tests indicated by Mr. Walker was really of great use to the foundryman in many respects, but he felt that what was of the greatest importance of all was the application of such knowledge to their foundry practice. He (Mr. Roxburgh), in the course of the lecture, had looked forward with interest to Mr. Walker's tentative specifications for the moulding sands. In regard to the specifications for synthetic sands, he felt

that there was definitely a chance of the supplier being able to work to the limits specified, but, after all was said and done, when they were talking about raw sand, it was quite a different matter, as the sand was quarried in its natural state and varying properties could be expected. Speaking from his own experience of moulding sands for ironfounding, he felt that the supplier would have great difficulty indeed in complying with the specification as outlined by Mr. Walker. The trend in the iron foundry to-day, particularly in the repetition foundries, was definitely in the direction of synthetic sands. It would be agreed that such sands lent themselves to control, but he felt that, from experience of the natural sands they received into their own foundry, when one talked about grain size, moisture, bond strength, etc., the sands supplied were very far from the ideal in regard to lending themselves to control. He agreed with Dr. Skerl that the question of the ramming of the sands was a very important one indeed, and that the density of ramming in these tests, mentioned by Mr. Walker, should be varied as much as possible.

The Moulder's Technique

The technique of the moulder was wrapped up in the question of the different densities of ramming. He felt that that aspect of the matter could not be stressed too much. Mr. Walker specified some compositions, mechanical properties, etc., for sands to be used for castings of a certain weight, and he wondered whether it might not be useful to include in that specification, too, the sections of the metal. If one took oil sand, for instance, one knew that, with a certain section of metal, the oil sand was insufficiently refractory, and he felt that that was rather an important point which should therefore be included in a specification. For his own benefit he would be interested if Mr. Walker would indicate to him a suitable sand that was used in a steel foundry for the moulding of some particularly large casting. He himself had been

responsible for the manufacture of a large cast-iron anvil block, and he wondered if Mr. Walker would inform him of a suitable type of sand for such a large casting made in steel.

Creating Internal Standards

Mr. Walker said he thought he had made it fairly clear that with regard to raw moulding sands, they could have a series of such sands which would all be satisfactory to the foundry when mixed with different silica sands, the proportion of silica sand naturally depending upon the raw material with which they started. In this respect it was clear that they could not possibly have any single specification covering all the raw sands in the country. If, however, they were using a particular kind of raw sand obtained from a particular bed, it would be a comparatively easy matter to test the raw sand as they received it, and find out which consignments gave satisfactory results and which did not. They could then base their specification on the properties of the satisfactory consignments, and ask the suppliers to supply sand only to that specification.

It was true that such a specification would not be applicable all over the country, but it would certainly be of considerable value to the particular foundry concerned, and could no doubt be easily extended to other foundries, using the same sand, and doing similar work. With regard to the weights of castings mentioned in the Paper, he had indicated the weights as showing the type of work for which the sands were intended, the weight of castings being such a commonly quoted figure, but actually it was the section of the metal which was important. When he referred to a casting weighing a few ounces or a pound or two, it was clear that it could not have a very heavy section, but he did not think that he could give precise values for the actual thickness of section, since the actual disposition of the different thicknesses in a casting altered the effect on the sand during the casting operation. Regarding very large

steel castings, he was afraid that he could not give specifications for sands to be used for these. In their foundry they followed the usual Sheffield custom and made castings of many tons weight in "compo."

Cost of Local and Remote Sands

Mr. F. E. Steele said Dr. Skerl had mentioned the fact that owing to various districts having different qualities of sand there would be considerable difficulty experienced in setting any one specification as being standard. That, to his mind, was one of the difficulties that founders were up against constantly. No doubt most of them would like to use on special jobs sand that they were not able to use owing to the high cost of the delivery of that sand to their particular district. In his own case he recalled an instance where they were recommended for a special job to get a sand that was admittedly well known as a good sand, but the price for delivery to his district was prohibitive. They accordingly experimented, and he was glad to say that they secured good results. He took it that Mr. Walker intended to convey that in Sheffield for similar classes of work they would use similar classes of sand.

Institution of Private Specification

Mr. Walker quite agreed that standard specifications of universal application could not be put forward at the moment, but what he was concerned about was the principle of making and using specifications for sand supplies. If Mr. Steele in his foundry established testing apparatus to examine the different sand mixtures he was using, he would be able to find what values of the tested properties gave him satisfactory results with his sand mixtures, and then would be able to make up a private specification to which he could work in his own foundry. He could then test the different batches of sand he made in the foundry, to see if they were satisfactory before going on to the foundry floor. The result of testing his mixtures would, however,

depend on the properties of the raw sands he was using, so that he would next have to examine the raw sands, find what their properties were, and see whether the consignments were uniform as they came in.

The Lead of the Mechanised Foundry

Mr. H. Wharton said that the reason the ironfounder lagged behind in the testing of sands was because his product was not so costly as steel, and he did not examine his waste as carefully as the steelfounder did. He was sorry, though, that he had not said a little more about the amount of water that might be found in some of the consignments of sand he had received, and also a little more about the importance of the moisture content of the sand on the shop floor. Those who had been associated with mechanised foundries would already have recognised the importance of the control of sand, and the beginning of that control was the testing for moisture content. That had an important effect on the properties, such as permeability and strength. Then there was the question of specification. As Mr. Walker had said, that was a local matter, but it was a very necessary one. Mr. Walker would probably find it more difficult when he had to make a specification for some of the clays for the bonding of his sands. That was a point they would come to probably in the near future. Some of the tests Mr. Walker had done were not exactly suitable for shop work, but they gave a great deal of information for use when buying new sands. He thought that, when they had had time to consider the figures, they would more thoroughly appreciate the work that Mr. Walker had put into his Paper.

Moisture Content

Mr. Walker agreed that the moisture content of sands was very important, especially in consignments of sands as received. Sometimes it happened that sand was loaded into wagons

and delivered to the foundry in a very wet state, the water increasing the cost of the sand. It was the general practice to convey sands mixed ready for use in covered wagons, but he had seen them sent in open wagons, and in such cases the moisture content sometimes rose to a very high figure. In the case of silica sands, after being received, they ought to be dried, so that the people in the foundry knew how they stood before adding any water. In the case of batches of sand mixed in the foundry, he agreed that it was most important, especially with green-sand mixtures, to test individual batches, and the easiest thing to arrange in practice was to have a boy somewhere near the mill, so that as each batch was mixed, he could test it on the spot. This, with a "Speedy" moisture tester, would not take more than 5 min. If it was satisfactory, the sand could be sent into the foundry, if it were not, it could be corrected before use.

He agreed that constructing specifications for clay would be more difficult than for foundry sands. It could not, of course, be done from chemical analysis alone. In his view, however, specifications could be constructed by using a known weight of a particular clay, mixing it with a specified amount of a standard silica sand, and finding the properties of the resulting mixture. The difficulty at present was that there was no such thing as a standard silica sand. If such a standard silica sand could be prepared, it would be useful in many ways, but its actual preparation was by no means an easy matter.

Vote of Thanks

Mr. S. Leetch proposed a vote of thanks to Mr. Walker. He said he was sure that Mr. Walker would not say that they could run their foundries from the laboratory. At his (Mr. Leetch's) own foundry they had solved a difficult problem in getting a good skin on small stainless castings by using the methods that Mr. Walker had expounded that evening and with the good offices of Mr. Hurst. They were doing a great

deal of research work, and there was room for a great deal more, but it would have to be the handmaiden of the practical man who had had years of experience and had learnt by his mistakes.

Mr. A. V. Goddard seconded, and expressed the opinion that steel founders ought to work from a dry base and then they would be able to control their own moisture.

The vote of thanks was carried, and in reply Mr. Walker said that whilst he fully agreed with the remarks of Mr. Leetch that some old moulders dealing with the same sand mixtures year after year could tell as the result of very long experience whether a sand mixture was satisfactory or not by inspection and feel, it was a fact that such practical men of great skill were becoming rarer and rarer. The actual workers in the foundry would in the future have to be supplied with more and more technical assistance from the laboratory. It was a regrettable fact that owing to the modern trend to mechanisation and for various other reasons, the number of craftsmen of the old high standard was steadily diminishing.

East Midlands and Sheffield Branches

FURTHER NOTES ON DEFECTS IN STEEL CASTINGS*

By C. H. Kain (Member)

The literature of steel-casting production is gradually growing, and the metallurgy of both the melting and after-treatment processes is well known. The physical and mechanical properties obtained are excellent, and compare favourably with worked steels; indeed, for some uses, such as heat resistance, there are indications that cast steels yield better results than forged steels. For special purposes and properties a wide range of alloy steels is now available to the founder, and these enable almost any test for service requirements to be met.

Unfortunately, the technique of casting production is not so definitely settled, and for this reason many of the modern publications appear to deal solely with the general inferiority of steel castings. The majority enlarge upon defects in steel castings and a few deal with methods of overcoming them. This is not the place to criticise these various publications and Papers, but it may safely be said that the nature and occurrence of steel castings defects are now widely known, and that future writers and investigators will be rendering most service to the industry if they devote themselves to discussing methods of overcoming these defects. A series of Papers, each containing a study of one type of defect only, would be of the utmost value.

Principal Defects

The three chief defects troubling the steel-founder are firstly cracks, secondly draws,

* See "Proceedings, I.B.F.," Vol. XXVI, p. 501.

thirdly gas holes. The term "gas holes" is here used to indicate cavities caused by gases arising directly or indirectly from the mould or mould materials. Many of these may truly be termed blowholes, and are caused by such things as excessively-damp moulds, wet external and internal chills and impermeable sands. Others arise from trapped gas caused by excessive pouring speeds, incorrect gating and uneven flow of

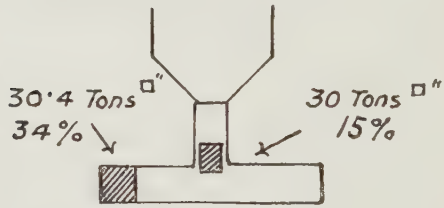


FIG. 1.—WEAKNESS DUE TO FREEZING AND COOLING PHENOMENA.

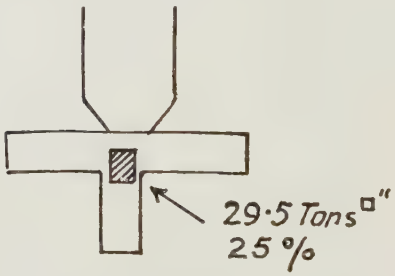


FIG. 2.—SHOWING HOW FEEDING CAN IMPROVE MECHANICAL PROPERTIES (JEFFERSON).

metal in the mould. The type of gas hole commonly called "sponginess" or "porosity" has been widely discussed and written upon, but has not been considered here because the remedy lies in the working of the furnace and melting procedure. The cavities are similar to those which are deliberately made in running steel for certain types of ingot, and if this is borne in mind they are easily prevented. There are

numerous other possible defects, of course, but these three are the most important, and also the ones over which the moulder has the greatest control.

Cracks

Dealing first with cracks, it was stated in a Paper* that all cracks could be put under four

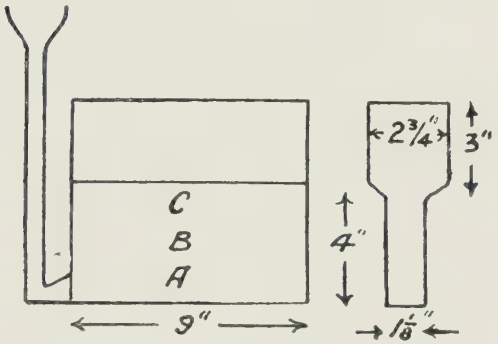


Fig. 3.—Test-Block used for obtaining Figures Detailed in Table I.

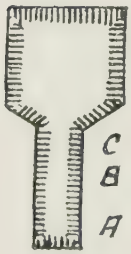


Fig. 4.—Illustrating Possible Reason for Test-Bar Strength Variations.

broad headings:—(1) Cracks caused by carelessness and lack of provision to allow for obvious contractions; (2) cracks caused by inadequate feeding, usually at a change of section or a re-entrant angle; (3) plain contraction cracks resulting from the casting behaving differently

* "Proceedings, I.B.F.," Vol. XXVI, p. 507.

from expectation, and (4) cracks caused by weakness of metal section.

Of these, the first and third call for little comment, as the causes are well understood and the methods of prevention within the power of every workman.

The second cause is not so easily disposed of, as this crack is closely related to plain shrinkage or draw, and also in many cases to blows or gasholes. Fortunately, it is easily overcome by the provision of a feeder or, better still, designing the casting so as to cause progressive freezing away from the seat of trouble. Quite probably this suggestion contains the whole cause of this type of defect, in that a study of the cooling rates of the various adjacent portions of the casting will show that progressive freezing *does* take place, but towards the possible seat of trouble. In many cases this effect is accentuated by the enclosure of a small portion or section of sand, causing a local heat reservoir and hot spot. In addition to the localisation of the shrinkage in this place due to heat conservation, it is often easier for mould gases from the small peninsula of sand to blow their way into the hot pasty metal than to force their way backwards through the body of the mould. As the metal is partially solidified and the primary dendrites formed, the cavity takes the form of a narrow, jagged hole in the corner of the casting, and is frequently mistaken for a tear or a draw. The absence of the characteristic smooth appearance of the usual blowhole is deceptive. If the design of the casting and the position of the defect is such as to allow the placing of a feed head above the defect, the trouble frequently disappears, though it is difficult to say without a study of each individual case whether this is due to feeding the pipe which tends to form or to allowing the gas ready escape through a larger bulk of liquid metal.

The fourth main cause of cracks, weakness of metal section, shown in Fig. 1, does not refer to weakness of design, but to inherent weakness

in the metal section, resulting from the phenomena of freezing and cooling. Mention of this was made by Mr. Jefferson at the Symposium* on Steel Castings held in Glasgow. To illustrate the point, Fig. 2 shows how adequate feeding improves the properties of the material, being the same casting reversed, and with a test-bar cut from the same place. These results are, of course, on the annealed casting. In both cases the casting appears solid and sound to all ordinary methods of examination.

In 1927, the author showed that, even in the ordinary block cast for test-bar purposes, there are remarkable and striking differences between adjacent bars. Fig. 3 shows the test block re-

TABLE I.—*Strength at Places Indicated in Fig.* 3.

Position.	Y.P. Tons per sq. in.	M.S. Tons per sq. in.	Elong. per cent.
A	20.48	31.86	34
B	21.06	31.48	24
C	20.28	31.48	28
A	20.28	33.64	31
B	19.72	33.52	22
C	19.40	33.04	26

ferred to, with dimensions and method of running, and Table I the results quoted.

In Fig. 4 is shown a diagram which was an attempt to explain the cause of the difference in strength of the various bars cut from the same block. It was suggested that as the metal cools it freezes in a continually-thickening envelope on all sides. The first crystals or dendrites formed conduct the heat away from the liquid in the centre, which then solidifies and carries the process a little further. A point is quickly reached when there is a very thin column of liquid metal in the centre, and the heat is conducted away from this so rapidly that crystallisation starts almost simultaneously down the full depth of the block from centres

* "Proceedings, I.B.F.," Vol. XXII, p. 623.

independent of the original dendritic walls. As these last crystals form and cool, they contract and rely on liquid falling by gravity from the head to feed the minute spaces left, but the pressure and fluidity of the metal in the head is only sufficient to force its way a short distance down. It will be seen then that since bar A

TABLE II.—*Blocks Cast on End as Shown in Fig. 5.*

No.	M.S. Tons per sq. in.	Elong. per cent.
G. 1–1	30.4	26
G. 1–3	26.04	11
G. 1–5	26.16	12
G. 1–7	24.84	9*
G. 1–9	27.12	16
D. 2–1	30.12	27
D. 2–3	26.72	9*
D. 2–5	26.12	10
D. 2–7	26.6	14
D. 2–9	27.28	14

* Drawn.

TABLE III.—*Blocks Cast on Side, as Shown in Fig. 6.*

No.	M.S. Tons per sq. in.	Elong. per cent.
G. 3–1	29.28	24
G. 3–3	22.68	7*
G. 3–5	26.88	10
G. 3–7	25.92	11
G. 3–9	28.92	16
D. 4–1	29.04	27
D. 4–3	22.76	12
D. 4–5	24.16	10
D. 4–7	25.24	10
D. 4–9	27.88	21

* Drawn.

freezes from all three sides, it consists entirely of primary crystals, while the centres of bars B and C consist of secondary crystals. The feed metal from the head has fed bar C efficiently, but it appears that bar B is inadequately fed in the centre.

In order further to investigate this question it was decided to cast a number of test-blocks

of exaggerated size and to take bars for examination. This test-block was 14 in. by 7 in. by $1\frac{1}{4}$ in., the thickness being that required when a specification called a 1-in. square-bend piece. This bar was cast in various positions and in both green- and dry-sand moulds. Four of the results are given as being representative. Figs. 5 and 6 show the position and size of feeder heads used. Ten bars were cut from each casting and tested in the as-cast condition. Tables II and III show the results obtained.

Owing to an error during machining of the test-bars, only the odd numbers are available. But these show clearly that the metal in the middle portions of the block has much less strength and ductility than the ends, which either freeze from three sides or, in the case of a top bar, are adequately fed from a header.

In order further to investigate the question it was decided to modify the shape of the test block to ensure further penetration of the primary crystals in the middle portions of the block. This is shown in Fig. 7. Sufficient material was left at the two ends of the block to cut bars as before, because in every case previously the two end-bars had shown the maximum properties. Two blocks were cast, one on end and one on its side, each with the same size of header as was previously used on the parallel blocks. Tables IV and V show the results.

It will be seen that, although theoretically the bars cut from the thick portion of the block away from the feeder should yield inferior results, they have, in fact, given results comparable with those obtained in parallel bars. The bars in the centre are much tougher than the similar bars cut from a parallel block. These results are, of course, from the completely-cooled casting, but it is reasonable to assume that the strengths and ductilities of the various portions of the casting will bear the same relation to one another when hot and immediately after freezing, as they do in the cold state. This fact may account for many cracks or tears which occur in parallel sections of a casting, and it is suggested that in castings of such thickness that it is not

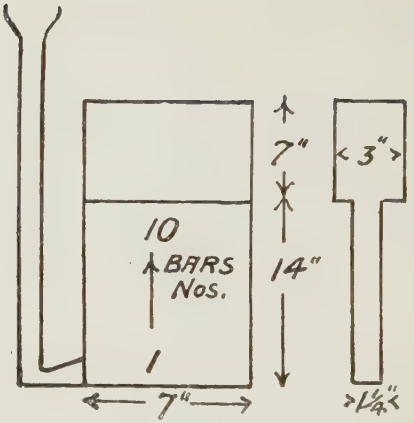


FIG. 5.—TEST-BLOCK FROM WHICH THE FIGURES SET OUT IN TABLE II WERE OBTAINED.

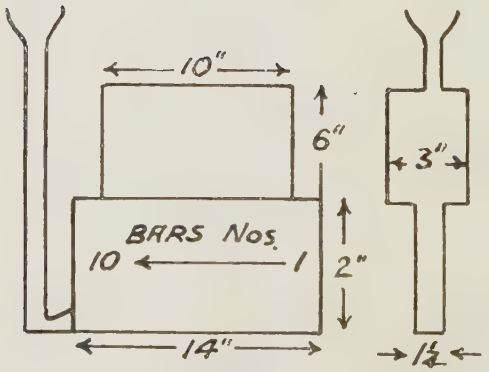


FIG. 6.—TEST-BLOCK FROM WHICH THE FIGURES DETAILED IN TABLE III WERE OBTAINED.

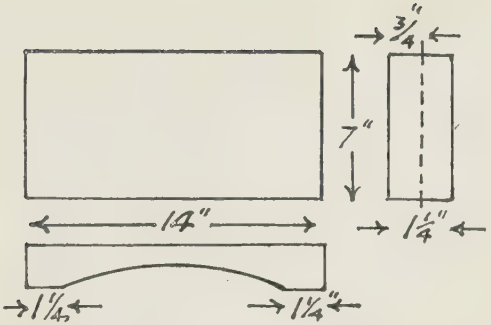


FIG. 7.—MODIFIED TEST-BLOCK, THE RESULTS FROM WHICH ARE DETAILED IN TABLES IV AND V.

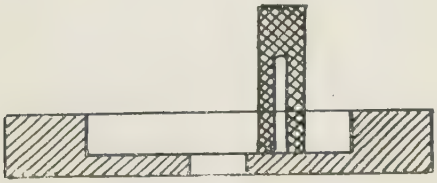


FIG. 8.—SMALL FLYWHEEL TYPE OF CASTING.

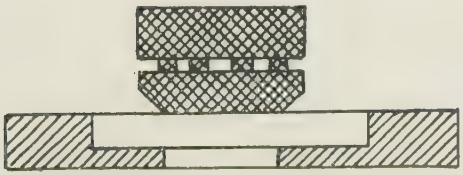


FIG. 9.—APPLICATION OF PENCIL GATING TO THE CASTING SHOWN IN FIG. 8.

possible to ensure (i) all the section being formed or primary crystals, or (ii) adequate feeding of the shrinkage of the secondary crystals in the centre, greater safety and increased strength in the casting will be obtained by modifying the section on the lines indicated.

The principles underlying the prevention of draws or shrinks are perhaps better known than those governing other defects in steel castings. At the time of writing (September, 1934) a series of Papers are projected for the International Foundry Conference in America, many of which deal with this subject. Various of the technical journals have published excellent articles on the matter, and last year the first part of a comprehensive survey was published in America and in THE FOUNDRY TRADE JOURNAL ("Studies on Solidification and Contraction and Their Relation to the Formation of Hot Tears in Steel Castings," by Briggs and Gezelius).

Pencil Gates

The phrase "progressive solidification" sums up the whole matter. By this the author understands so arranging the design, gating and feeding of the casting that freezing takes place progressively towards the feed heads provided. This is the principle discussed when dealing with the weakness of metal sections, and shows that cracks and draws are very closely allied. In another place a number of applications of this principle have been described, and it is not proposed to repeat them here. Mention may be made, however, of the use of pencil gates. Very frequently the use of a number of small gates in the upper portion of a casting gives excellent results with very small headers. An example was given last year where the head was reduced from 50 lbs. to 24 lbs. by the use of $\frac{3}{8}$-in. dia. pencil gates. The use of pencil gates on steel castings must not be confused with those sometimes used for grey iron. The writer freely admits that he does not fully understand the mechanism of the action of pencil gates, but it may be broadly stated that, with grey iron, the object is entirely to

eliminate headers, while with steel the object is to reduce them to a minimum by progressive solidification. This may best be illustrated by an example, Fig. 8, which illustrates a not uncommon type of small flywheel casting. In grey iron this may be made perfectly solid, without headers, by the use of pencil gates on the lower

TABLE IV.—*Block Cast on Side, as Shown in Fig. 7.*

Test No.	M.S. Tons per sq. in.	Elong. per cent.
1	33.92	17
2	29.9	10
3	32.6	12
4	32.9	13
5	31.1	10
6	32.6	11
7	33.0	12
8	32.5	11
9	25.7	4*
10	33.4	15

* Flawed.

TABLE V.—*Block Cast on End (Fig. 7).*

No.	M.S. Tons per sq. in.	Elong. per cent.	Remarks.
10	31.68	17	—
9	31.52	12	—
8	31.52	12	—
7	31.68	11	—
6	30.48	9	—
5	29.20	6	Drawn.
4	26.32	5	Badly drawn.
3	24.44	4	,, ,,
2	22.16	4	,, ,,
1	34.34	21	—

thin portion of the casting, provided that the iron is of suitable composition. Fig. 9 shows how it would be necessary to use pencil gates if the casting were in steel. It must be made clear that pencil gates are not recommended for this particular casting in steel, because, although it would be possible to make the casting sound with

a very small header, it would probably have a very bad surface, due to scabbing and local fusions of sand. But the design shows an excellent example of the essential difference between pencil gates for grey iron and those for steel.

It is often stated that the ingot is the simplest form of steel casting. This is not so, because the ingot is approximately parallel, and it is often difficult to ensure progressive solidification, hence the use of such aids as heavy chill bases, tapered moulds and sand or firebrick heads. The simplest form of steel casting is the wedge, with the sharp end down. In this case there is definite progressive freezing towards the open end, where it is a simple matter to provide an adequate head. If this illustration is borne in mind it becomes easier to visualise helpful modifications of design and correct gating and feeding.

Blowholes

Much has been said and written at various times on the subject of blowholes, and all authorities are agreed that, apart from porous or spongy places due to wild and insufficiently-deoxidised steel, nearly all blowholes are caused either directly or indirectly by the mould materials. These include the sand or compo of the mould, and cores and such extras as facing and dressing materials, horseshoe nails, chills both external and internal, and runner bushes. Personal experience of " compo " moulds is somewhat limited, so the following remarks apply particularly to sand moulds, though they might apply to " compo " also.

Blowholes caused by the condensation of moisture upon chills and nails call for no comment. There is no excuse for their occurrence, although it is often not realised how quickly beads of water condense upon nails and chills after a mould is closed. Sometimes blowholes are caused from the formation of iron oxide on the surface of nails and chills during the drying of a dry-sand mould, which reacts with the carbon in the steel to form CO and CO_2. Here again, the trouble is so obvious that there is no excuse for

not ensuring that the film of oxide is removed before casting.

It has been suggested that many blowholes are caused by the entrapping of air or gas due to the high pouring velocities common in the steel foundry. The writer has shown that, owing to the high velocity of the steel entering the mould, it is possible for the steel to flow to the furthest extremities of the mould and climb the sides of the mould, so entrapping a bubble of gas as shown in Fig. 10. This phenomenon appears to be independent of pouring temperature, having been observed with both hot and cool metal. The theory was evolved before sand-testing became common in this country, and in the light of results now obtainable appears to require modification. One would expect that when using a very highly permeable sand escape of mould gases would be so easy as to ensure all gases passing away through the mould before the incoming rush of metal. In spite of this, the defect has been observed when using a sand with a permeability of 300 to 350 (obtained on Richardson's apparatus). Experiments were then made with a sand of much lower permeability, 160 and under (which appears to be the lowest practical limit as scabbing of the mould begins to appear). The defect was still encountered on certain types of casting, the greatest freedom being obtained with a sand of about 200 to 300 permeability. In all these experiments the nature of the sand was the same, being Yorkshire sand of a strong grade mixed with clean silica sand of varying degrees of fineness, and being maintained at a moisture content of 2.5 to 3.5 per cent. with a strength of 6 to 8 lbs. per sq. in.

Another phenomenon which was observed when using the open sand was the presence of cold-laps on the surface of the casting, particularly on inner surfaces on or near to a heavy section on a thin section, as shown in Fig. 11. This suggests that possibly the rapid expansion of the large volume of air enclosed in the sand mould caused back pressure on the surface of the

incoming metal which formed a crust through which fresh metal forces its way in the centre, as shown in Fig. 12. Another suggestion is that

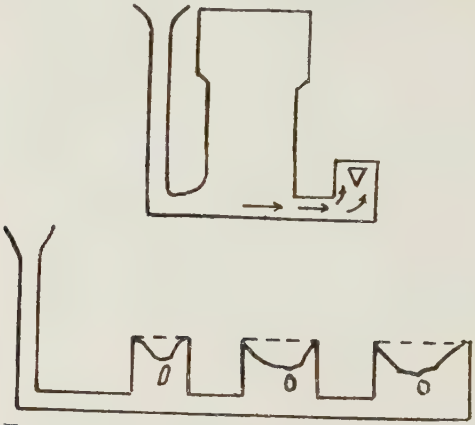


FIG. 10.—SHOWING HOW GAS BUBBLES MAY BE ENTRAPPED.

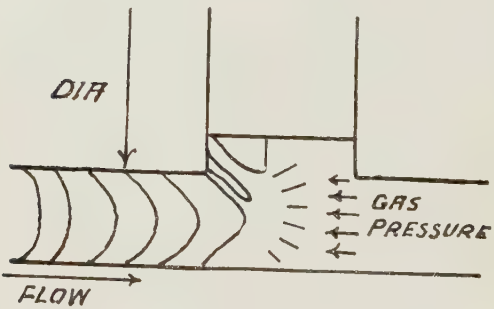


FIG. 11.—PHENOMENON OF INFLUENCE OF BACK PRESSURE ON SOUNDNESS.

the very open nature of the sand allows such rapid escape of the gases as to cause a partial vacuum in the mould, and the hotter metal in the centre of the incoming stream rushes through

to fill the gap, overlapping the cooler metal nearer the mould surface. Or, again, that the large volume of air conducts heat away from the metal surface more rapidly than the close sand of

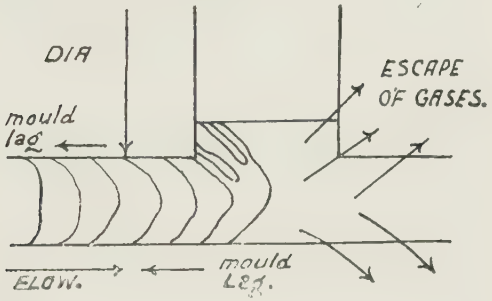


Fig. 12.—Diagrammatic Explanation of a Cause of Air-Trap Defect.

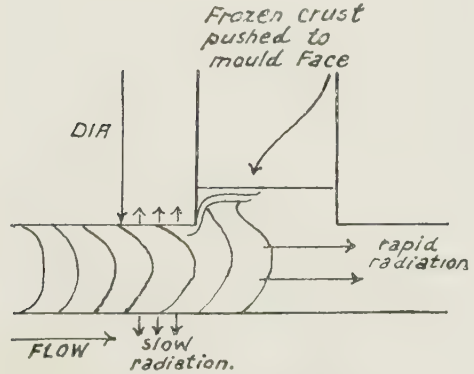


Fig. 13.—Showing Formation of Laps through Radiation.

a dense mould, and so forms laps or roaks, as shown in Fig. 13. All these ideas may be made to fit in with the suggestion that the rapidly-flowing metal travels to the extremities of the mould and encloses a space. In the case of a

dense mould there is no doubt that expansion of the mould gases causes internal pressure in the mould, and that the metal, travelling in this volume of high pressure, flows round the outside and encloses a bubble of gas. It is noteworthy that in the low-permeability moulds no cold-lapping was observed. This also may agree with the high-pressure theory of the open sand, in that with the open sand the metal may force the high-pressure gas backwards through the mould and so allow lapping, whilst with the dense sand the resistance of the mould is too high to allow spurts of metal to force their way through the general surface of the liquid.

Perhaps these ideas are too fantastic to be true, but it is hoped that they may at least form the basis of constructive discussion.

DISCUSSION BY SHEFFIELD BRANCH

Entrapped Air

The Chairman (Mr. J. E. Hurst) opening the discussion, said that he was particularly interested in what Mr. Kain had said about the question of the entrapped air buffer on the boss at the extremity of one of the castings he had dealt with. The air buffer was apparently drawn from it in the shape of a pipe. He was not sure whether he understood Mr. Kain correctly when he was explaining his own theory on the subject, but he understood him to say that his theories had undergone a certain amount of modification in the light of sand testing. Apparently, Mr. Kain had experienced some difficulty with sand. As he understood it Mr. Kain experienced difficulty with sand of a high-permeability number. He would like to know if he (Mr. Hurst) interpreted Mr. Kain's remarks correctly when he assumed him to mean that the difficulty alluded to was minimised when the sand was of a lower permeability number. If that was so it fitted in with some experiences of his own in regard to newer alloyed cast irons that had shrinkage values similar to steel. He had definitely found that with very

fine-grained sand they were getting much better results than they had got when using sands of a very open nature. He had not been able to account for it, but it was a fact that they obtained greater freedom from those cavities, whether they were entrapped areas or shrinkage cavities. He would like Mr. Kain to give them a little more information on that point.

Mould Drag

Mr. F. E. Steele said he was very interested in the question of mould drag, especially in regard to thin castings. He definitely attributed to mould drag a great many of the difficulties they had experienced in the running of thin castings, either in steel or cast iron, more especially in regard to green-sand moulding. One thing that impressed him was the pressure exerted in front of the stream of steel or iron, as the case might be, and he agreed with Mr. Kain that this was a very vital point. In his view, if they could reduce that back pressure, they would be going a long way at any rate towards removing some of the difficulties of the internal cavities. Shrinkages, of course, they found more in steel than in cast iron, but even in cast iron they found internal shrinkages. He thought that Mr. Kain would probably agree that those internal shrinkages very often were not due to the structure of the material used so much as to the fact that the air generated inside the mould collected there and could not release itself. Moreover, he thought that in many cases the forming of cavities could be overcome by the method of pouring. For instance, if they poured a mould, say 18 in. from the runner, and then poured the same mould only 6 in. from the runner, it was his belief that they would be tending to draw in from the atmosphere air that would eventually go into the casting.

Sand Permeability Requirements

Mr. Kain said the casting that Mr. Hurst had mentioned consisted essentially of a large boss with a branch on it and a small boss

attached. He apologised if he had not made himself quite clear on this. The cavity was perfectly round and smooth. The trouble described was first noted before any sand testing at all was done in this country. They were then using a very coarse silica sand from Leighton Buzzard which had a permeability of considerably over 300—probably 400. Undoubtedly the trouble was less with a less permeable sand. In his opinion they would require a closeness of about 160 in steel casting sand. With sand below that figure they seemed to have trouble. He apologised to Mr. Steele for not talking much about mould-drag. Undoubtedly mould drag was a serious matter, particularly with thin steel castings. It certainly caused cracks to form. The friction of the castings against the sand was very much greater than was often realised. Sometimes it was found that the runner was actually pulled away from its normal position. This meant that the bulk of the contraction had been away from the runner instead of, as was usually supposed, towards it. He did not know that the mould drag was more serious with green sand than dry sand mould. In fact his experience was rather in the contrary direction. He agreed with Mr. Steele that the question of the metal flowing down the runner was not seriously considered, or at least not as much as it ought to be. A casting which in grey iron would normally be run in a matter of 55 to 60 seconds, in steel would commonly be poured in 6 or 7 seconds, and the pouring velocity must accordingly be correspondingly higher.

Mr. G. Offiler said the points put forward were new to him and certainly must be considered along with the mould criticism put forward from time to time. The drag appeared widely on the surface of the casting as shown in Mr. Kain's illustration. It was very puzzling as to why this should be so.

Mould Drag and Surface

Mr. Kain said that undoubtedly Papers on steel casting for many years had not produced

anything new. For this reason they had rather marked time as compared with those who gave Papers on grey-iron and non-ferrous metals. It was not the case that roughness in steel castings was due to the drag. It was due to the inferiority of the sand, to the excessive heat of the metal or something like that, and the drag was accentuated by the roughness of the casting. Even in the case of a perfectly smooth casting and one which had an excellent casting skin, the lag was very pronounced. In some instances he had found castings, 4 or 5 ft. long, with a perfectly smooth skin cracked for no apparent reason. The only possible explanation was that there had been friction between the metal and the mould.

Contraction of Steel Castings

Mr. E. J. Brown said, in connection with Mr. Kain's remarks, a series of American Papers had just been issued, among which was one by Briggs and Gezelius on "Free and Hindered Contraction of Carbon Steel." This Paper was, in the speaker's opinion, something of a classic, and should be of theoretical interest to all steel foundrymen. The chief points which would appear to emerge from the experiments which had been conducted were:—(1) Contraction decreases as the carbon content increases. If, however, contraction should be hindered, as is possible in the case of castings, the carbon content has little effect; (2) majority of the contraction takes place before the critical range is reached; and (3) by preventing freedom of contraction, that is, by restraining, using springs for the purpose, the linear contraction was reduced from about 2.5 to 0.5 per cent., apparently without fracture.

He (Mr. Brown) mentioned this latter point in order to point out that, after all, there seemed to be a fair amount of flexibility before fracture takes place, due to contraction. With regard to Mr. Kain's test-bar experiments, it was

obvious that the best ductility figures were obtained from the portion of the bar which was quickest to cool. He did not wholly agree with Mr. Kain's reasoning on the matter, but was inclined to the view that the variable results obtained were the result of the influence of non-metallic inclusions.

Carbon Content and Contraction

Mr. Kain agreed that the Paper by Briggs and Gezelius on the contraction and solidification of steel castings was undoubtedly a classic. He did not think he could agree entirely with the deduction of Briggs and Gezelius as to the contraction becoming increasingly less with increase of carbon in the steel casting. He thought it was so small as to be negligible. In ordinary steel castings up to perhaps 0.55 or 0.60 per cent. C.—ignoring the special high-alloy steels—the contraction differences were remarkably small. He agreed with Mr. Brown's explanation of the better results obtained on the bottom bars of a test-block. They did give better results and consisted entirely of primary crystals. As they formed the crystals tended to drive inclusions before them.

Recommend Permeability

Mr. T. R. Walker said he did not think he agreed entirely with Mr. Kain's remarks about non-metallic inclusions. It was, of course, a fact that primary crystals would drive inclusions in front of them, but it was also known that the lower half of an ingot was precisely the place where they would find most metallic inclusions. This had been established by the Iron and Steel Institute beyond doubt. He was interested in Mr. Kain's remarks about the properties of his sand, and agreed that 200 to 300 was a very good permeability number for general green-sand work. The practice of those with whom he was associated was to run about 220 to 270, but in some heavier castings it was necessary to go below that and below Mr. Kain's 160, and in

these cases they found they could get quite good results with sand having a permeability number of 130, or even 120.

Incidence of Water Vapour

Mr. Kain said he could not say with certainty that in any of the test-bars to which he had referred he had troubles that he could directly attribute to non-metallic inclusions. What he had suggested was that that action did take place and was, perhaps, a contributory cause. He was not prepared to say that that action took place to any pronounced extent. He merely suggested it as a possible explanation. The figure of 160 he had quoted was for permeability of green sand only, and he took it that the larger castings to which Mr. Walker had alluded were dry. Unfortunately he (Mr. Kain) did not know what the properties of dry sand were.

With regard to the possibility of low gas pressure in the mould cavity, Mr. Kain said that this might be caused by the rapid condensation of water vapour which always took place a short distance back from the mould face.

Cracks on Corners

Mr. C. J. Dadswell said he was interested to hear Mr. Kain's theory in regard to cracks on corners. He himself gave a Paper recently and put forward exactly the same theory—that the cracks one found at corners had been caused by the penetration of material into the steel from the strongly heated corner sand, the sand becoming excessively heated because there were two right angles. Many of the faults were due, as Mr. Kain had said, to the effect of trapped gas.

Mr. Kain said that they were often deceived by the fact that the little cavities that appeared to be cracks had sharp chipped angles. This was due to the gas forcing its way in when the metal was in a partially frozen state. This could be very efficiently overcome by reversing the casting and feeding it on the top, or better still by doing away with some of the sand altogether.

Dr. J. G. A. Skerl remarked that it seemed to him that a great many of the troubles which Mr. Kain had indicated were due to the effect of the solubility of oxygen and steel. It was a fact that metal seemed to flow better in a green sand mould than in a dry sand mould.

Mr. Kain said he was grateful to Dr. Skerl for his suggestion as to the probable cause of the flow of steel in the case of green sand.

Mr. A. V. Goddard proposed a vote of thanks to Mr. Kain. This was seconded by Mr. A. Whiteley and carried unanimously.

Scottish Branch

SOME FACTORS WHICH INFLUENCE SOUNDNESS IN NON-FERROUS CASTINGS*

By A. Logan (Member)

The ordinary brasses and bronzes—alloys of copper and tin and copper and zinc—like the poor, are always with us. Many articles are made to-day of similar composition to alloys made 5,000 or more years ago, and it is a certainty that many of the common foundry troubles now being experienced were suffered by those very early pioneer founders. In the copper-tin series, alloys containing more than 25 per cent. tin are useless—being too weak and brittle. There is a rough sub-division which is usually made into gunmetal containing from 8 to 15 per cent. tin, and Bell metal containing from 14 to 25 per cent. tin. Gunmetal, as its name implies, was the material used for the manufacture of guns before the invention or discovery of iron or steel. Practically all guns, wherever manufactured, consisted of a straight copper-tin alloy, usually ranging from 92 per cent. copper with 8 per cent. tin to 89 per cent. copper and 11 per cent. tin. Even in later mediæval times, apparently it was known that the range 8 to 11 per cent. tin gave the best combination of strength, elasticity and shock resistance.

Admiralty Gunmetal

The material known as Admiralty gunmetal to-day has 2 per cent. zinc incorporated, giving a composition of 88 copper, 10 tin and 2 per cent. zinc. The zinc is added mainly as a deoxidant and to give increased fluidity. This alloy is of universal application, and is used

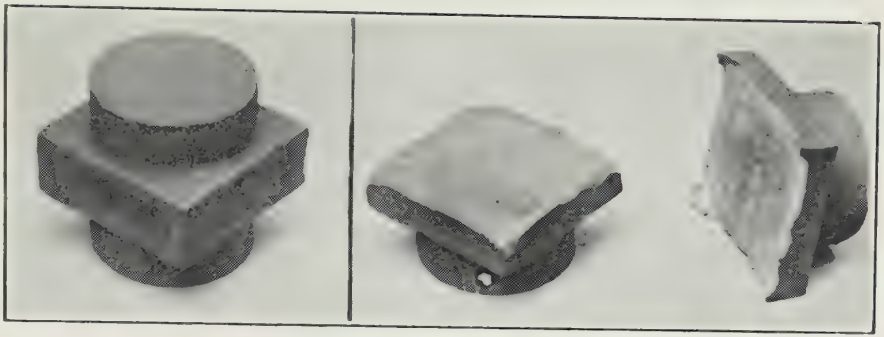
* Slightly abridged.

extensively in all branches of engineering. The present Admiralty specification calls for 16 tons per sq. in. tensile and 8 per cent. elongation, and under good conditions these figures are easily attained.

A few years ago, the Admiralty specification asked for 14 tons per sq. in. and 7 per cent. elongation; and it is quite conceivable that at some not-far-distant future date this specification may again be further increased. The strange thing is that the alloy remains exactly as it has always been, and the material going into the casting is still 88:10:2; and the increased physical properties are met by improved foundry technique and by knowledge of test-bar production. It is necessary to qualify this by the assurance that it is not suggested that increased test figures are obtained by any doubtful means or test-bar manipulation, but rather that the casting requires to be poured and run in such a way that the production of a sound and strong test-bar receives prior consideration. The conditions which produce the best bar may not necessarily produce the best casting to which that particular bar is attached. As an aid in the production of fluid metal, and sound, clean-run castings, phosphor copper is often used as a deoxidant, and definitely assists in this direction and is beneficial, providing not more is added than will leave 0.05 per cent. P in the finished alloy. On the other hand, phosphorus is definitely added in quantity to straight copper-tin alloys to increase the hardness and to improve the wearing properties of bushes and similar parts. Usually, the tin is fairly high in this class of alloy, being about 11 to 12 per cent. with about 0.3 to 0.5 per cent. phosphorus. In some cases the tin is as high as 14 to 15 per cent.

Too Many Specifications

Apart from two or three definite high-quality standard bronze alloys of these types, however, there are dozens and dozens of compositions resulting from the combination of the four metals, copper, tin, lead and zinc. Practically every

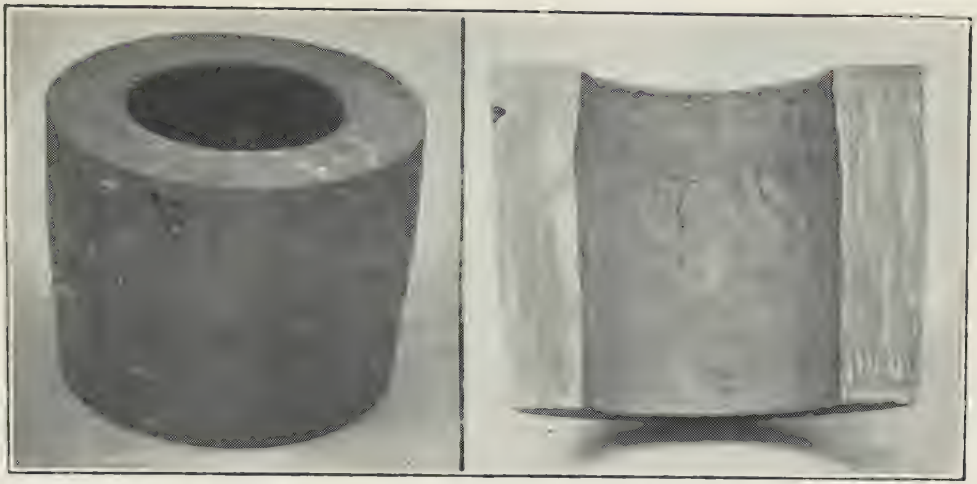


FIGS. 1 AND 2 SHOW A CASTING, WHICH, THOUGH APPARENTLY SOUND, SPLIT, DUE TO OXIDE FILM, ON MACHINING.

public body, and every firm which buys non-ferrous castings, issues its own specifications or has its own particular idea as to what compositions it requires for its own particular job. Many of these compositions differ from each other by variations of only 1 per cent. or less, and it is obvious that in many cases there is neither rhyme nor reason for the variations asked for by different specifying bodies for the

Fig. 3.—Type of Casting Used in Density Determination Experiments.

same class of casting. This state of affairs makes the life of the brassfounder very trying. In a large foundry where many different compositions are required, and are going through simultaneously, it requires very good organisation and much care to ensure accuracy of individual mixtures, and the greater the number of compositions going through, the greater the work involved, not only in the initial issuing of materials, but in the care of returns and foundry scrap, etc.



FIGS. 4 AND 5.—SHOWING THE INFLUENCE OF METHODS OF RUNNING UPON SOUNDNESS OF CASTING.

Extra care and attention mean increased cost, and as a great amount of the extra work involved is unnecessary, or would be so if the number of mixtures in use were restricted, there is here indicated a real need for further standardisation. Many firms on the highest class of work, especially where already doing Admiralty work, adhere to the Admiralty standard gunmetal, allowing themselves perhaps a little more latitude in the lead content. The B.S.I. have a gunmetal specification which is very little lower than the Admiralty standard. (There is a little more latitude as regards what the Admiralty are pleased to call impurities, otherwise the same physical properties are required.)

It is obvious that this does not completely meet the needs of present-day engineering practice where low costs and economical production are the prime factors; and a move is now being made to have a range of additional bronzes standardised. The composition of the already existing B.S.I. gunmetal is 88/10/2. The suggested range would have decreasing amounts of tin and copper and increasing amounts of lead and zinc, the physical properties being graded accordingly. An additional range of leaded phosphor bronzes is likewise under consideration, where increasing amounts of lead would be specified. The ultimate adoption of the proposed new alloys and the eventual use of these alloys in industry, will go a long way to simplifying the work of the non-ferrous founder, and will provide a more uniform product with definite physical properties at a cheaper cost.

Causes of Unsoundness

Turning now to a direct consideration of some of the causes of unsoundness, it would be a fairly safe generalisation to state that there is no such thing as a perfect casting—that all castings, whatever the material, suffer from defects of one kind or another. Sometimes these defects are obvious, often they are not so obvious. The majority of defects are usually internal and may not be revealed by machining. They may

not even be revealed by a pressure test, in which case the casting is said to be a "good" casting, and goes into service. It may, in actual service, prove perfectly good enough; and it may only be years later, at the close of its useful life, when the casting lies in pieces on the scrap heap, that the mysteries of its "guts" are exposed. In this connection, a few minutes spent examining sections and fractures of broken scrap can be very illuminating.

Year by year the demands of engineering become more exacting, and new alloys are constantly being evolved to meet the increased demands, but it is necessary for the manufacturers of even the ordinary common alloys to keep a very careful eye upon their products and strive to increase the soundness and reliability of all castings. Before one can say that a particular casting is defective, one should be able first of all to define a perfectly sound casting. Primarily it should be a perfect replica of the original drawing or pattern from which it is made, as regards shape and size. The material of which it is made, at atmospheric temperature and pressure, should occupy a certain definite volume; that is to say, the specific gravity should be the maximum for the particular alloy used. This latter point is probably the most vital factor of all as regards soundness of castings. If the specific gravity of a number of cast pieces of the same alloy be determined, it will be found that the pieces vary. Portions even of the same casting will be found to differ.

Percentage Waste

In general, one could state that the perfectly sound casting does not exist, *i.e.*, that the total specific gravity of a casting is hardly ever the maximum possible for the alloy, nor is it the same in all parts of the casting. This discrepancy is due to the presence of looseness or cavities constituting unsoundness ranging from an overall porosity where the size of the cavity is microscopic and the numbers enormous, to the

isolated holes or porous patches which are sometimes encountered. The cavities may be filled with extraneous material, such as slag, oxide inclusions, sand or dirt from the mould, or they may be gas filled, or even the opposite—partial vacua. One is tempted to ask what is the average percentage of faulty castings produced? This, of course, is a matter which varies considerably from foundry to foundry, according to the class of work made, the purpose for which the castings are required, the alloys they are cast from, and the skill and degree of scientific knowledge or control exercised. Taking a specific

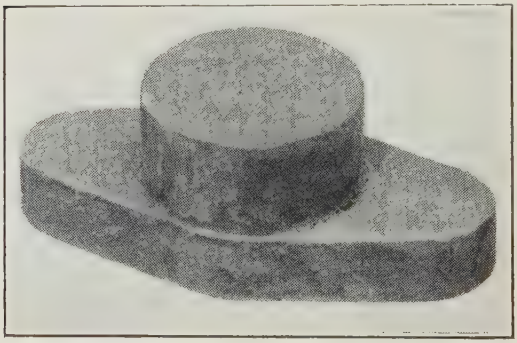


FIG. 6 SHOWS A DEFECTIVE VALVE BRIDGE.

case—the production of fittings such as cocks and valves, etc., in Admiralty gunmetal, anything in size up to about $\frac{1}{2}$ cwt.—the percentage of wasters from all causes in personal experience does not exceed 1.5 per cent. The normal figure is round about 1 per cent., and under this figure can be considered to be very good practice. There are other classes of work with other alloys where a figure of 5 per cent. would not be considered excessive.

It is often very instructive to analyse the causes of faulty castings. Here, again, it is difficult to generalise, as the purpose for which the casting is made plays such a big part. Parts

which require to be machined will naturally be rejected if the machining reveals any unsightly marking due to occluded dirt or sand, or if sufficient machining allowance is not available through misplacement or movement of cores, etc. On the other hand, a casting which is subjected to a pressure test has this additional hazard following after the machining, so that the chances of failure are very much increased. Actually, as might be expected, the majority of wasters are discovered on water test—the pro-

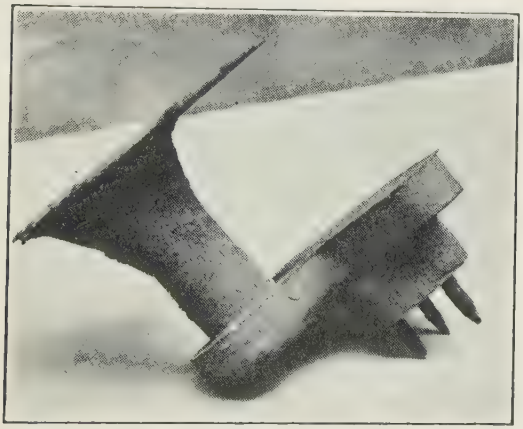


Fig. 7 shows the Method of Running Used to Eradicate the Defect shown in Fig. 6.

portion of " porous " castings to castings defective by reason of what may be termed purely moulding faults or difficulties being somewhere in the region of 3 to 1. It would take too long to enumerate in detail all the causes of defective castings, even if such were completely known, but the following are some of the most important. To be logical, one should start at the designing end, but as this involves a consideration of basic principles, it will be left until later. Purely moulding defects are usually

fairly obvious. Such things as leaving out small cores, incorrectly setting a core, or a movement of a core when casting due to flotation, part of the mould breaking or washing away when pouring, etc., are elementary and easily accounted for, and can prove very annoying and wasteful in practice. Such things as warped patterns or coreboxes can result in much waste time, and even scrapped castings when the castings are small and/or the machining allowance very fine.

Defects from Sand

The actual sand used has a vital influence on the soundness or otherwise of the resulting casting, particularly when "batch" or mass production is in operation; and this matter is receiving more and more attention nowadays. Sand control alone can be the means of directly lowering the percentage of faulty castings turned out. There is a tremendous number of troubles which can occur due to moulding, and, when once the casting has been removed from the mould, the cause is anything but obvious, and in some cases becomes almost impossible to trace. The manner in which the moulding of a particular casting is tackled—the method of running and gating are vital points. The method of moulding is usually settled at the pattern-making stage, after collaboration between the patternshop and foundry, and the same basic principles which should be kept in mind when designing are applied. Even given a perfect pattern, however, one is still dependent upon the individual skill and care of the actual moulder to a considerable degree. Granted, however, the possibility of a mould which is capable of giving a correctly-dimensioned casting, there are still a large number of snags which can prevent the attainment of that ideal —the perfect casting.

Melting and Mould Conditions

The melting of the particular alloy will require to be carried out with care. All non-

ferrous alloys are very susceptible to oxidation at high temperatures, and tend to absorb oxygen and other gases during melting. This can cause trouble through the separation of oxide films during solidification, and evolution of gas can occur prior to, and during, solidification. In addition to gas absorption during melting and its liberation during solidification, there is also the large evolution of gas from the material forming the walls of the mould to contend with. In green-sand work, too high a moisture content of the sand, or the excessive use of the swab in finishing a mould, are ever-present danger potentialities, and have to be continually controlled. A dry-sand mould *should be a dry-sand mould*, yet how often "inquests" reveal that the risk was taken. These practical moulding difficulties are the merest foundry platitudes, but long experience has shown that they can never be entirely eliminated. Every faulty casting analysis over a period will show its percentage of wasters from such causes, and it depends entirely upon the degree of supervision as to how low this percentage can be kept.

There is also the possibility of clumsy pouring, or a wrongly-shaped pouring basin creating turbulence which can carry free air down with the stream of metal into the mould. This is a much greater hazard with non-ferrous alloys than with cast iron. An interrupted, or broken pour, too, is almost invariably fatal. Where there are a number of small castings in a box, careful arrangement of the running is desirable to avoid what amounts in effect to a broken pour.

An Unexpected Defect

Sometimes some of the castings near the runner may almost fill up; then a rush of metal occurs to others farther away, with the result that the first castings are partially drained. When they finally fill up again, the additional metal may not unite perfectly to the original, and curious effects are sometimes observed. One such casting, which looked perfect when removed from the mould, came in two halves when

machining commenced, and was found to be separated by a complete oxide film across the section. This is illustrated in Figs. 1 and 2.

Fluidity

Fluidity, or, more properly, the viscosity, of the liquid metal, and surface tension effects vary considerably from alloy to alloy. If the metal be sufficiently fluid, for instance, any entrapped air or liberated gas will have a much better chance to escape. This brings in a consideration of the casting temperature, as the fluidity and viscosity are dependent to some extent upon the degree of superheat given to the metal. In general, every alloy has its own range of safe pouring temperature. This is often quite considerable, as in the case of Admiralty gunmetal, where the range for normal foundry working is from 1,100 to 1,220 deg. C. This does not imply that any casting can be poured in this range and good results secured. Each casting definitely has its own correct casting temperature, which will depend upon the size, section and mass of the object to be cast.

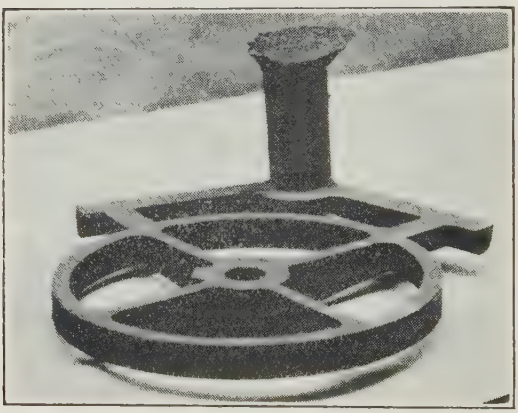


Fig. 8.—The Small Boss on the Centre Hub caused Difficulty with this Casting.

In many cases, especially where there are big differences of section, it is obvious that the particular casting temperature chosen must be a compromise; and this is where foundry skill and experience count, for the running and feeding must be so arranged that the casting is completely filled with metal that is hot and fluid

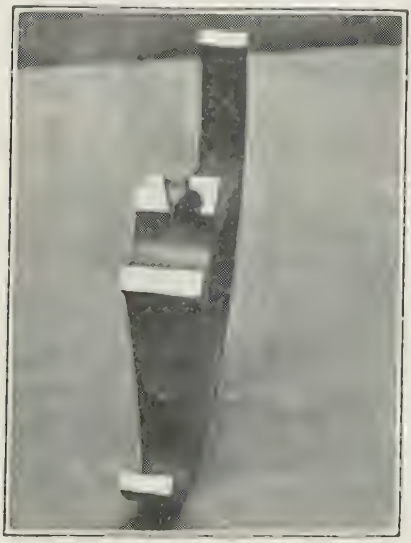


FIG. 9 SHOWS THE NATURE OF THE DEFECT NOTED IN FIG. 8.

enough to run the thin sections perfectly, yet not to have excessive superheat in the thicker sections. The feeding of thick sections must also be arranged to cater for the liquid shrinkage which occurs on a falling temperature before solidification. For this reason, it is necessary to arrange that the solidification takes place as far as possible progressively from outlying sections in towards feeding points.

Solid Cooling

Liquid metal, whilst cooling in a mould, undergoes three definite phases. There is the period immediately after the mould is filled, when, if only for a second or two, the mould space is filled with a rapidly-cooling liquid. All liquids decrease in volume whilst cooling, and liquid metal is no exception. Little definite data are available, however, of the extent of this liquid shrinkage. In any case, it is to be presumed that the metal still being liquid, loss of volume is made good by further inflow of metal from the feeding head or gate. If solidification of the feeding head or gate take place before the casting, then a " pipe " will be found extending into the casting when the gate is broken off.

The second phase is reached when the liquid metal commences to solidify. All substances which crystallise on freezing undergo a volume change at this point. Metals and alloys usually contract considerably, although there are certain well-known exceptions, such as bismuth and its alloys. Very little is known of this phase, but it is of paramount importance from the foundry point of view. It should be remembered that crystallisation always proceeds at a right-angle from the cooling surface of the mould. When the mould is filled with molten metal, the cold sand forming the mould walls immediately commences to abstract heat from the liquid in contact with it. It will be obvious that the higher the superheat of the metal the greater the amount of heat there will be to be imparted to, and dissipated by, the mould. As sand is a very poor conductor, the rate of cooling to the atmosphere is slow, so the effect of greater casting temperature is to give, in effect, slower cooling. Bronze has an extended freezing range, and as the outer layer of metal is cooled by contact with the mould wall, the temperature of solidification is reached and dendrites proceed to grow inwards into the cooling metal. The primary dendrites form a solid net work which gradually thickens and extends inwards. As the temperature falls, secondary dendrites branch out, and from these

other dendrites proceed to fill in the spaces. As the solidification is proceeding, the volume is decreasing, as the solid dendrites occupy less space than the molten liquid from which they are formed. As long as any liquid remains at the centre of the section it will flow through the spaces between the branches of the dendritic "trees," so to speak, though with increasing difficulty, and make good this solidification contraction. It is essential, therefore, to ensure that each section is fed with still liquid metal, to make good this demand. This is the reason that, as far as possible, progressive solidification from the most remote part of the casting back to the runner or feeding head should be arranged for.

The third phase is the decrease in size of the solid casting as it cools down to atmospheric temperature. This does not take place uniformly, but is greatest at temperatures near the freezing point, decreasing as it nears atmospheric temperature. This is the reason that it is essential to free the cores of large moulds immediately solidification is complete. At this temperature the alloy is extremely weak, and any restriction at all will result in tearing the casting apart.

Controllable Variables

The variables which the foundryman has at his disposal after the design of the casting is fixed, are the way up he decides to mould it, the arrangement, size and number of runners and feeding heads, and the casting temperature. The casting temperature normally fixes the rate of cooling, but to a slight degree the rate of cooling may be varied by means of chills to compensate for unequal section.

The crystallising habits and structure of the particular alloy dealt with also require to be considered in relation to design, in order that the casting be given every chance to be sound and free from internal stress (and not, as many foundrymen believe when they receive a new

pattern of strange and weird shape, to be expressly designed to do the very opposite). Extreme changes of section are always very difficult to obtain completely sound. The ultimate criterion of a casting is the actual structure of the alloy forming it, and this depends upon all the factors which operate to produce the casting itself, right from the initial design, moulding, pouring, casting temperature, solidifica-

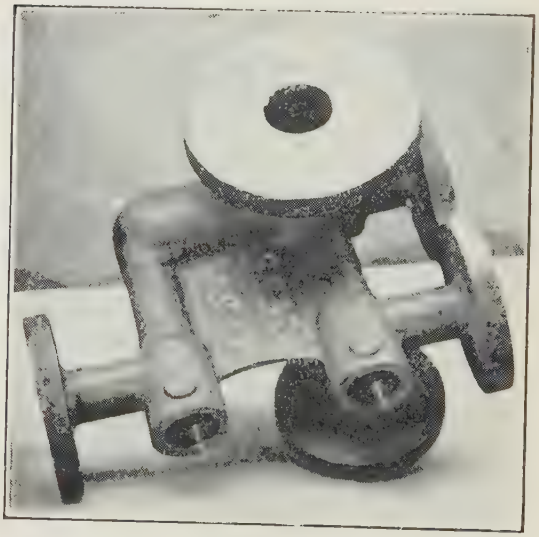


FIG. 10 SHOWS A CASTING, LIABLE TO DEFECTS THROUGH EXCESS RIBBING.

tion, and the final rate of cooling down to atmospheric temperature. Most alloys which consist of solid solutions possess dendritic structures "as-cast," and Admiralty gunmetal is quite a good example.

It has been amply shown that the best physical strength of bronze is reached at an optimum medium casting temperature. The exact temperature at which the peak occurs for any particular alloy is determined by the composition,

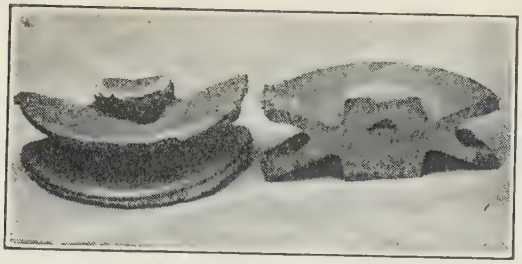


Fig. 11.

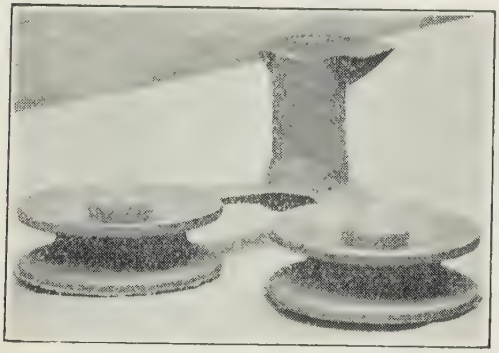


Fig. 12.

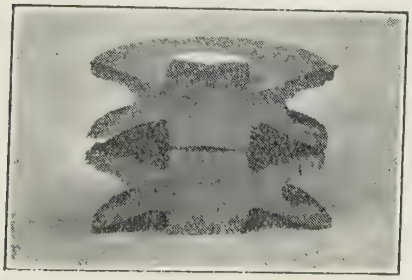


Fig. 13.

Figs. 11, 12 and 13 show a Defective Casting (11); an Improved Method of Running (12), and the Resultant Good Effect (13).

casting temperature, shape of bar, method and speed of pouring, rate of cooling, and other variables. It is now well known, however, that the hardness and density increase as the casting temperature is lowered. Figures published by Rowe* show that the effect is partly one of rate of cooling. The more rapid the solidification, the higher the Brinell figure, and also the greater the density.

Density of Castings

It is this question of density which is so important where castings are subjected to pressure tests, and time spent investigating the conditions of running, to give the maximum density, is well spent. Where batches of large numbers of castings off the same pattern are going through, an excellent opportunity occurs of studying this matter, and checking the effect of varying casting temperature and alternative methods of gating.

Where a number of moulds are poured from one crucible or ladle, there must be a falling temperature gradient between the first and last poured. If the castings are dissimilar, they will naturally be arranged so that those requiring the highest pouring temperature will be cast first. Where the castings are identical, then a safe pouring range will have to be found and adhered to. With small work and optimum running and gating conditions, this latitude can be surprisingly large, as evidenced by taking the first and last casts from a batch of oil-sprayer bodies. Nine identical boxes, containing a pair of sprayer bodies were cast from a crucible. The pouring temperature of the first box was 1,170 deg. C., and the temperature of the last, 1,120 deg. C., a drop of 50 deg. during the time taken to pour the whole batch. The castings are illustrated in Fig. 3. The specific gravity of the complete casting poured first at 1,170 deg. C. was 8.73., whilst the last was 8.77. These castings require to be as perfect as possible, as they are machined all over, and are then

* "Proceedings, I.B.F." Vol. XXVII, p. 318.

subjected to a fairly high-pressure test. Any drop in specific gravity is immediately reflected in an increase of rejects on test. This high and consistent density figure is only possible owing to the fact that the casting is relatively small, and is run very direct, with an ample gate and head. The bulk of metal in the runner is actually greater than the casting. Larger and more intricate castings are a very different proposition, and are much more affected and susceptible to casting temperature.

The tendency of the moulder is to work with too small a runner and gate. This is possibly due to unofficial pressure from the fettling-shop end. The official view should be that, whilst obviously desiring to keep the fettling costs down as much as possible, it is false economy and bad practice to permit small gates or runners, with the consequent loss due to "piped" and unsound castings, or subsequent failures on water test. Sometimes "flows" or feeding heads are used unnecessarily, and to the detriment of the casting. Where used indiscriminately, or without appreciation of the principles involved, they can do far more harm than good. An example is shown in Fig. 4, which is a pipe-end in flange metal. This was originally run from the bottom with a small ingate. A "flow" was taken off from the top of the casting, at right angles. When cleaned off, the casting was found to be "piped" where the top "flow" was broken off. This can be seen in the illustration. A sunken place was also found a short distance below the top, extending all round the inside. There were contraction cracks also at several places round this band, as shown in Fig. 5. Repeating this without any attempt to provide a feeding head, but after considerably enlarging the ingate and down tube, put matters right.

Keeping in mind the principle that it is essential to obtain progressive and uniform solidification back over towards feeding points, it is sometimes necessary to resort to some chilling device to even-out the rate of solidification of thicker

sections. The trouble that can be met in this direction is shown by an example where a solid boss of 2-in. dia. occurs on a casting of only $\frac{3}{8}$-in. section. Fig. 6 illustrates a bridge piece for a valve. It might be argued that the trouble is intensified by the lack of a fillet, but whilst this is so, a fillet does not eliminate the trouble. The only satisfactory method of securing this sound has been to run with a very ample "gate" and chill the boss, as shown in Fig. 7.

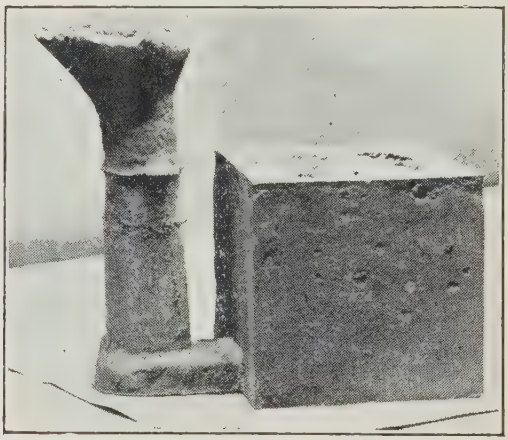


FIG. 14.—SIX-INCH CUBE (TABLE I), BOTTOM-RUN.

The same trouble is met with where end flanges are thickened up out of all proportion to the body of the casting, and this, it should be noted, is an increasing modern tendency. Flanges of 1 in. thick, for instance, are found on small "T" or branch pieces, where the general body section is a matter of $\frac{3}{16}$ in. or $\frac{1}{4}$ in.

Another example of a casting which gave trouble is shown in Fig. 8, which illustrates a strainer centre. This has a small boss on the centre hub, which is drilled and tapped to take a grub screw. The extra thickness at this spot

apparently allows a lower rate of solidification, and the arms of spokes feed from this still liquid portion, giving rise to a feeding contraction cavity (Fig. 9). The only remedy is to speed up the rate of solidification to that of the arms by inserting an internal chill.

Another type of trouble occasionally met with is the use of too many or redundant ribs on castings. A casting such as that illustrated in Fig. 10 can give considerable trouble. The thin

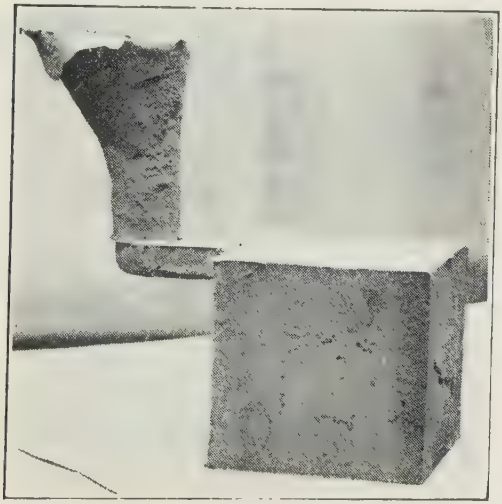


Fig. 15.—Six-inch Cube (Table I), Top-poured.

flat rib cools more quickly than the body of the casting, and the solid contraction tends to disturb or even rupture the crystallisation where it joins on to the body, with the result that it is difficult to avoid leakage on test at this junction. An application of what is known as " pencil gating " is found to work very well on certain types and shapes of castings. Fig. 11 illustrates a trolley wheel, which suffered as shown. By running these on the thin flange,

as illustrated in Fig. 12, with a runner an inch by an eighth, these were obtained quite sound, as shown in Fig. 13.

Experiments on Cubes

As an experiment in gating and running, a series of 6-in. cubes were cast under various conditions. No claim is made that the series is conclusive. They were simply made to test out

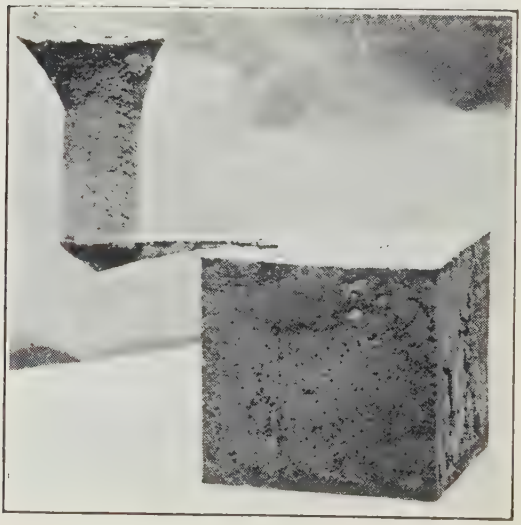


FIG. 16.—SIX-INCH CUBE—FREAK GATED (TABLE I).

one or two ideas, and the results (Table I) are merely placed on record as being of interest. The first batch of three were cast to indicate a temperature effect. They were run at the bottom with a gate measuring $2\frac{1}{4}$ in. by 1 in. These were poured at 1,145 to 1,100 and 1,065 deg. C. respectively. The maximum depth of the top depression and specific gravity of the whole cube are shown in Table I. It will be seen that the density of the lowest—that poured at 1,065

deg. C.—is very satisfactory; in fact, it is actually the best of the whole series made.

The depths of "sink" do not exactly follow the casting temperatures for some reason or other, although, as would be expected, the greatest "sink" occurs with the highest pouring temperature. Nos. 4 and 5 were cast with the same size gate, but run from the top. It was realised that with this size of gate it would not be desirable to exceed 1,100 deg. C., so only the two were cast; one at 1,105 deg. and the other at 1,050 deg. C. In this case, the depth

TABLE I.—*Experiments on Six-inch Cubes.*

	CASTING TEMPERATURE	POURED	SIZE OF INGATE	HEAD	CONCAVITY AREA	CONCAVITY MAX DEPTH	SPEC GRAVITY	REMARKS
	1065°C	BOTTOM	2¼"×1"	4"	4" DIA	11/16"	8·566	
2	1110°C	BOTTOM	2¼"×1"	4"	4"×5"	½"	8·323	
3	1145°C	BOTTOM	2¼"×1"	4"	4"×4"	13/16"	8·39	
4	1105°C	TOP	2¼"×1"	6"	3½" DIA	11/16"	8·344	
5	1050°C	TOP	2¼"×1"	6"	3" DIA	½"	8·35	
6	1150°C	BOTTOM	1"×½"	6"	4"×3½"	½"	8·24	
7	1130°C	BOTTOM	1"×½"	6"	5½"×5½"	¼"	8·52	4½" DIA HEAD FED WITH ROD
8	1150°C	TOP	1"×⅛"	6"	5"×5"	9/16"	8·31	
9	1100°C	BOTTOM	1"×½"	6"	4½"×4½"	5/10"	8·33	4½" DIA HEAD

of depression does follow the casting temperature, the hotter poured one having $\frac{11}{16}$ against $\frac{1}{2}$ in. for the one at 1,050 deg. C., but the strange thing is that the specific gravities were practically identical.

Another pair were cast using a very small gate—only 1 in. by $\frac{1}{2}$ in. One was cast without any attempt to feed it, and the other had a $4\frac{1}{2}$-in. diameter head put on the top. When the cube was filled, the runner was stopped off, and the head filled direct from the crucible and rod feeding resorted to. To counteract for the small gate size, the casting temperature was

raised to 1,150 deg. C. It was expected that the cube without any feeding would be unsound when sectioned, but such was not the case, the higher temperature apparently compensating fairly well for the small gate. The density was certainly low, however, being only 8.24. Cube No. 7 fed with a rod was very satisfactory, having a "sink" of only $\frac{1}{4}$ in. and a specific gravity of 8.52, this being the best of the series.

As an example of freak running, another cube was run from the top with a gate only 1 in. by $\frac{1}{8}$. This again, in spite of expectations to the contrary, proved to be quite sound when sectioned, the "sink" being $\frac{9}{16}$ and the density 8.31. To determine whether rod feeding was really effective in this case, a final cube was cast as nearly as possible the same as No. 7, but without resorting to rod feeding. The temperature unfortunately was 30 deg. lower, but it is not considered that this explains the big difference which was found on comparison. A ring of deep holes was found all round the junction of the head with the top of the cube, and the density was only 8.33. A comparison of this cube with No. 7 fully justifies the use of rod feeding under such circumstances.

The following illustrations show the method of making the cubes:—Fig. 14 shows the bottom-poured set, Nos. 1, 2 and 3; Fig. 15 the top-poured pair, Nos. 4 and 5; Fig. 16 the freak gate cube (No. 8), with a gate of only 1 in. by $\frac{1}{8}$ in.; Fig. 17 the freak gate cube, with a close up of head; Fig. 18 the cube (No. 9) with additional head, and Fig. 19 illustrates the sections through tops of the cubes showing the amount of "sink" in each case. In no case was any actual cavity or unsoundness found when the cubes were sectioned.

DISCUSSION

Tired Metal

Mr. J. Arnott said that, in regard to the question of oxidation during melting, modern practice had demonstrated that oxidising conditions were often preferable and that oxidation

was one of the least of the troubles in non-ferrous work and could be overcome. Some of the cases which Mr. Logan had illustrated were not all due entirely to shrinkage. His experience had been that all batches of metal do not behave in the same way. Some gave good results and others gave bad results; neither was casting temperature responsible in all cases, nor was it the sole controlling factor. There came into the picture the question of remelted metal

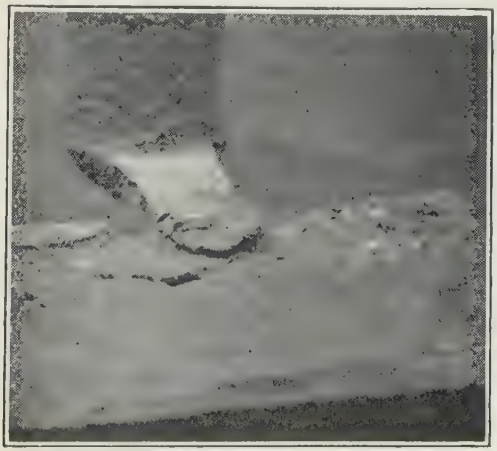


Fig. 17.—"Close up" of Gate of Block shown in Fig. 16.

and the difficulties of remelting heads and gates. The trouble was more marked in foundries doing light work; in heavy work there was a lower proportion to be remelted. It was a fact that metal which had been remelted a few times deteriorated in quality, and there was obtained what he called "tired metal." He suggested to Mr. Logan that some of the examples which he had shown were due to that factor. He would have been pleased if Mr. Logan had gone into

more of the question of scientific foundry control, as he understood that he had given a considerable amount of attention to the development of such a system of control. He would be glad if Mr. Logan could give some opinions as to the best methods of metal melting. Every week some new melting process came out which was claimed to be superior to any other. Would Mr. Logan give them his own preference for melting methods?

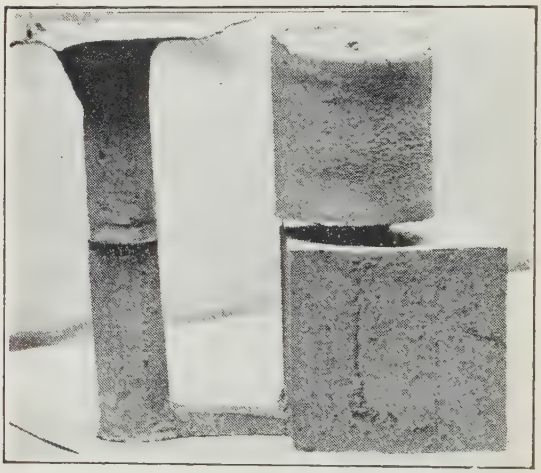


Fig. 18.—Six-inch Cube (Table I) Cast with an Additional Head.

Mr. Logan, in reply to Mr. Arnott, said that his references to oxidising melting were quite correct. It had now been shown that reducing conditions during melting gave more trouble and that at the same time the metal could suffer from oxidised metal. The conditions of castings were not always the same; sometimes it was necessary to accumulate large volumes of metal in the ladle. It was fatal with non-ferrous metals if the ladle was not absolutely dry. In regard to shrinkage, he was prepared to admit that not

all the defects were due to change of section, but some of them did certainly show the effect of section. There was a liability to tear from both ends of the scale. Admiralty gunmetal made from virgin metal was liable to tear, and also the same alloy made from metal that had been remelted. In some cases the metal tears because it is too new, and in some because it is too old.

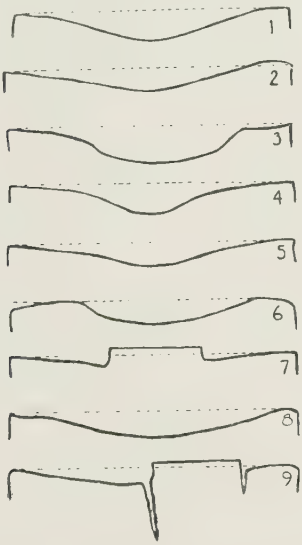


Fig. 19.—Sections through the Tops of the Six-inch Cubes (Table I) showing Resultant Type of Sink.

He was not prepared to advance any theory to explain it, but he thought that, as Mr. Arnott had mentioned, the metal got tired. In regard to foundry control, he had concentrated largely on casting temperature, as he considered that was largely the control needed in non-ferrous practice. He had instituted an elaborate system of temperature control with

very good results. He considered that temperature control was well worth doing. If they kept records and controlled temperatures, they came to a point where a definite improvement was obtained. He considered that all the metal in the foundry should be under one control. In respect of melting, he found that different people had different ideas as to what constituted a perfect method of melting. Personally, he thought that it would be hard to beat the crucible for speed of melting, but he had no very definite preference, and at the moment that matter was being investigated by him.

Mr. McCulloch said that he took particular notice of one of the slides, and asked what size of feeding head and gate Mr. Logan used. Also, he would like to know whether he used skim gates or drop gates.

Mr. Logan replied that he took it Mr. McCulloch meant the cubes. The bottom gates were $2\frac{1}{4}$ in. by 1 in. and the top gates the same size. The freak gate was 1 in. by $\frac{1}{8}$ in., which was very small. In the other experiment the bottom gate was 1 in. by $\frac{1}{4}$ in., with feeding head. In one case rod feeding was adopted, and in the other not. In runner gates of large size it was necessary to use a strainer core to keep the runner filled. Skim gates were not used—only the core.

Mr. Morehead said that he had experienced two little difficulties which had not been mentioned by the author. In making the 65/25 alloy with 5 per cent. lead and 5 per cent. zinc he had found a quantity of finely-distributed hard, dusty material. In naval brass he had experienced skin folding, due to an oxide skin. In a cylindrical casting the top edge in the length of the casting had what was apparently a crack, but was really just a skin defect. There was no doubt that certain trouble, whether they called it oxidation or not, such as metal spewing out of the top of the runner, was generally overcome by deoxidation.

Mr. Logan, in reply, said that he had not experienced the hard spots referred to by Mr. Morehead. They might get it with tin oxide formed during melting. In regard to the skin folding, he had no theory to put forward, and could not offer an opinion without seeing the casting. The trouble might be due to the use of a damp ladle. He had experience of that; the metal poured satisfactorily, and shortly after pouring came up to the top of the runner. The casting was very holed and showed a lot of tin sweat. Metal reduced by hydrogen gave a gas evolution in a very severe form.

London Branch

MANGANESE BRONZE AND BRASS

By Wesley Lambert, C.B.E. (Past President)

Historical

By the courtesy of Mr. Bernard Parsons, Director, and Mr. J. E. Newson, Chief Metallurgist, of the Manganese Bronze & Brass Company, Limited, the author is able to record a few authentic historical facts relating to the early introduction of manganese bronze and brass. It would appear that the first public mention of manganese bronze is to be found in "The Times" of February 21, 1876, wherein is cited the results of mechanical tests carried out at the Royal Arsenal, Woolwich, on certain new alloys introduced by the late Mr. P. M. Parsons. Judging from the figures published, the alloys tested on this particular occasion were definitely of the "bronze" type, *i.e.*, they were essentially copper-rich copper-tin alloys, to which manganese was added, most probably in the form of ferro-manganese.

A great future was predicted for the Parsons alloys, and in "The Standard" of April 12, 1876, it was suggested that possible applications would be marine propellers, locomotive axle-boxes, pressure pumps, pump-rods, racers for gun-mountings, and numerous other parts where steel failed by corrosion, and even armour plate for warships. With the exception of the last application, the alloys have fulfilled the prediction in a remarkable manner.

From subsequent records, one gathers that the first noteworthy application of the copper-tin-manganese alloy was the fitting, in 1877, of babbitted bearing brasses to the engines of the s.s. "Gleneagles," which vessel in the following year won the "Ocean Race of Tea Clippers from

China." In May, 1879, a comprehensive display of manganese bronze and brass products was exhibited at a meeting of the Institution of Civil Engineers at South Kensington Museum. The exhibits included rolled sheets, forged and rolled rods, wire, and castings for high pressure; also, a cycloidal propeller for a torpedo boat. "The Times" of October 20, 1879, describing a new yacht for the Czar of Russia, mentions the provision of a Parsons' metal four-bladed propeller of 16 ft. dia. and 20-ft. pitch. On February 18, 1881, the trial of the s.s. "Garth Castle" took place, this vessel being the first of the mercantile marine to be fitted with a propeller of the new metal. Two months later the new alloy superseded gun-metal for all future propellers for the British Admiralty.

One may infer that the development of the copper-*zinc*-manganese alloys was almost certainly contemporary with that of the copper-*tin*-manganese alloys, as the company founded in 1882 to manufacture the Parsons alloys was, and still is, called the Manganese & Brass Company. Of the two types of alloys, the bronze appears to have fallen out of favour, whereas the manganese brasses, now commonly referred to as "manganese bronze," rapidly became established and have long been regarded as among the most successful of the industrial high-duty alloys in everyday use.

Some Metallurgical Features of Manganese Bronze*

The composition of commercial manganese bronze will be found, in general, to be within the following limits:—

Copper	... ...	50 to 70 per cent.
Aluminium	...	Traces to 5 ,,
Tin	... ...	Traces to 1½ ,,
Iron	... ...	Traces to 2 ,,
Manganese	...	Traces to 5 ,,
Nickel	... ...	Traces to 3 ,,
Zinc	... ...	Remainder.

* The designation "manganese bronze," in all subsequent references, is to be understood to refer to those complex alloys of a copper-zinc basis, containing manganese, but more rightly described as manganese brass.

Lead, arsenic, bismuth, antimony and sulphur, even in small quantities, are undesirable constituents. The composition, the character of the microstructure, the grain size, the state of cleanliness of the metal, and the freedom from gas and "draws," are the important factors which determine the strength and suitability of a manganese bronze.

The manganese bronzes used for industrial purposes fall into three categories, distinguished by

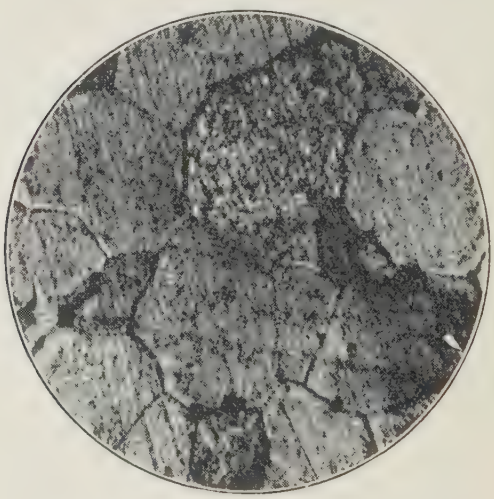


FIG. 1. — MANGANESE BRONZE, SHOWING A HOMOGENEOUS STRUCTURE, CONSISTING OF THE ALPHA CONSTITUENT. × 100.

their microstructure. These three classes are designated:—(1) Alloys of alpha structure; (2) alloys of alpha-beta structure, and (3) alloys of beta structure. Alloys of all three types are in use for the manufacture of rod and sheet, but alloys of alpha microstructure are rarely, if ever, used for founding castings to shape.

Under the microscope, suitably-prepared annealed specimens of the three categories of alloys will show, in the case of the alloys of the

first and third type, a ground mass of a single-phase constituent consisting of a solid solution of zinc in excess of copper; whereas, the alloys of the second category reveal a duplex structure consisting of the two microconstituents, alpha and beta, the former separating out from solid solution from the latter during the cooling of the alloy.

The proportion of zinc to copper, the percentage amounts of other metals present, and the

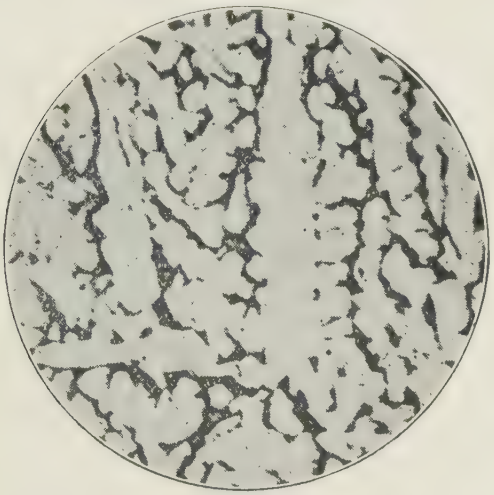


FIG. 2. — MANGANESE BRONZE, SHOWING A DUPLEX STRUCTURE OF ALPHA PLUS BETA (70 TO 75 PER CENT. ALPHA). × 100.

rate of cooling are the dominating factors which determine the ultimate microstructure of any particular manganese bronze. The influence of even only small percentages of additional metals upon the microstructure of a copper-zinc alloy may be very marked. In general, the ordinary metals found in a complex brass supplement the normal effect of zinc; aluminium and silicon are particularly active in this respect, and tend appreciably to disturb the normal relationship

existing in copper-zinc alloys between composition and microstructure.

It is essential, therefore, when attempting to compound a complex bronze of a definite microstructure, to take this fact into consideration. A copper-zinc alloy of the alpha-phase may be readily converted into one of the alpha-beta type by the addition of metals other than zinc; likewise, an alpha-beta alloy into one of the beta type, or even a beta alloy into the brittle beta-gamma phase; alpha plus gamma, however, cannot exist in the same alloy.

Given the coefficient of zinc or copper equivalence, as the case may be, for each of the added metals—provided that the quantity of a metal is within certain limits—the micrographical constitution of any complex brass may be ascertained by the use of simple formulæ.

The selection of the most desirable metals, as also the determination of their several percentages, in order to secure the desired microstructure and properties for a special duty alloy, particularly within the province of the metallurgist, involves time and much costly research to arrive at the best data.

Characteristics of Cast Alloys of the Alpha Phase

As previously indicated, copper-zinc alloys of the alpha phase, which are in perfect internal equilibrium, are of a homogeneous single-phase structure. Under ordinary conditions of cooling, however, the alloys are not truly homogeneous, but show the well-known "cored" structure, which may be regarded as their chief characteristic when viewed under the microscope. During solidification, the first crystallites formed are much richer in copper than the mixture, *per se*, and as crystallisation progresses, the portions solidifying are successively poorer in copper and richer in zinc than those which preceded them. Each crystal grain presents a more or less regular gradation from centre to boundaries, the centre being richer in copper and the

boundaries richer in zinc, than any other portion of the crystal. If the composition of the alloy approaches 36.5 per cent. of zinc, the boundaries of a crystal grain may become rich enough in zinc to show evidence of the beta phase between the alpha crystals. The cores and also any beta constituent may be absorbed, and the alloy rendered homogeneous, by suitable annealing. The melting or freezing point of an alloy of alpha microstructure may be taken as being about 895 deg. C.; the highest figure of the three categories of alloys under consideration. All the alloys of this class are characterised by the qualities of toughness and ductility. At ordinary temperatures these qualities attain a maximum when the zinc content is round about 30 per cent. Fracture of these alloys rarely, if ever, reveals the boundaries of the crystals, hence, even in slowly-cooled metals, these alloys show an extremely close-grained fracture. The yield point, as also the breaking load of the copper-zinc alloys of alpha microstructure is low, rarely exceeding 8 to 9 tons per sq. in. for the yield, and 26 to 28 tons per sq. in. for the breaking load. By the addition of small percentages of suitable metals, these figures may be conserved, coupled with an elongation figure of 50 to 60 per cent.

Characteristics of Cast Alloys of the Alpha-Beta Phase

Under the microscope the alloys of this type reveal a duplex structure of two micro-constituents, the alpha constituent appearing as long, irregular-shaped crystals, and the beta as somewhat larger polygonal crystals of more or less spherical proportions. In the alloys rich in copper, the beta constituent is often found at the boundaries of the somewhat tortuous alpha crystals. In the alloys rich in zinc, the beta crystals appear as massive polygons, at the boundaries of which alpha of various shapes and thickness segregates. Otherwise, the alpha constituent reveals itself in the body of the beta

grains, often occurring in characteristic feathery forms.

As in the case of the alpha alloys, the microstructure of the alpha-beta alloys is influenced by the rate of cooling. When an alpha-beta alloy solidifies, the solid metal, at temperatures immediately below the freezing temperature, is entirely of the beta phase, which on cooling to a certain definite temperature, dependent upon the chemical composition, commences to break up

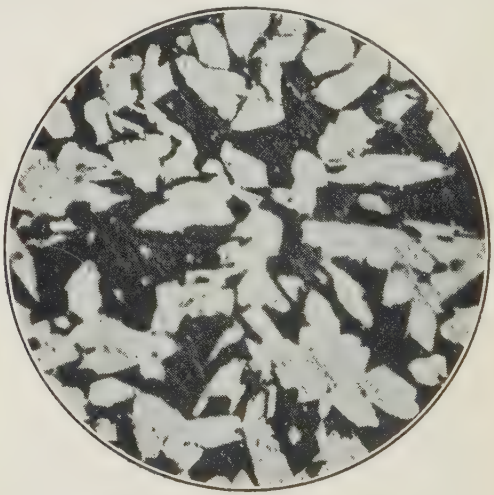


FIG. 3. — MANGANESE BRONZE, SHOWING A DUPLEX STRUCTURE OF ALPHA PLUS BETA (60 TO 65 PER CENT. ALPHA). × 100.

into a duplex structure. Should the cooling be too rapid, however, the alpha and beta phases will not be in complete equilibrium; the alpha phase will be deficient in amount, and the beta phase will be too rich in copper. Suitable annealing will enable the beta phase to throw out its excess of copper in the form of crystals of the alpha constituent.

The amount of beta showing in a micro-specimen of a copper-zinc alloy when in complete equilibrium, is proportional to the amount of zinc in

excess of 36.5 per cent. Thus an alloy with a zinc content of 36.5 per cent. of zinc exhibits no beta constituent. An alloy having a zinc content of 46.5 per cent. will consist wholly of the beta constituent. The quenching or very rapid cooling of an alpha-beta alloy *before* it has had time to throw out the alpha constituent may result in the formation of a homogeneous beta structure to the exclusion of any trace of the alpha constituent, notwithstanding that the alloy

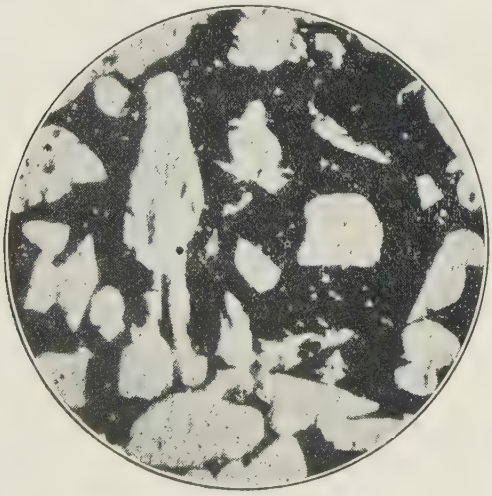


FIG. 4. — MANGANESE BRONZE, SHOWING A DUPLEX STRUCTURE OF ALPHA PLUS BETA (40 TO 50 PER CENT. ALPHA). × 100.

has the chemical composition associated with an alpha-beta metal.

A content of 1 per cent. of tin is specified by the British Admiralty in the specification governing the acceptance of high-tensile brasses of the alpha-beta type. The presence of the tin is considered to render the alloy more immune from the action of sea water. According to Desch, the tin is shared about equally between the alpha and the beta micro-constituents. In a correctly-compounded manganese bronze, the presence of

tin in such proportion as that mentioned is not revealed under the microscope. Increase of tin beyond 1.4 per cent. is inadvisable, as, when this percentage is exceeded, a segregate of Cu_4Sn may be detected. The melting or freezing point of alloys of the alpha-beta type may be taken as about 875 deg. C.

In physical properties, the alpha-beta alloys are intermediate between an all-apha and an all-beta brass, varying between the soft, tough and ductile alpha brasses, and the hard and more brittle beta alloys. By suitably modifying the composition of the copper-zinc alloys of duplex structure by small percentages of selected additional metals, a combination of the most desirable properties of each of the single-phase alloys can be secured. Alpha-beta brasses can be worked either hot or cold.

Characteristics of the Cast Alloys of the Beta Phase

The beta phase of the copper-zinc series is a wholly homogeneous solid solution of zinc in copper. Unlike the alpha constituent, it does not show any distinct evidence of a cored structure. Under the microscope, the etched metal reveals itself as a single constituent, consisting of massive, more or less regularly formed, polygonal crystals—octahedrons of the monometric system; the diversity of colour of the exposed crystal surfaces of an etched micro-specimen being dependent upon the particular orientation of the individual crystals. The limiting figures comprising the beta range of the copper-zinc alloys are 46.5 to 49.0 per cent. of zinc. At temperatures just below the freezing point, however, alloys with as little as 40 per cent. of zinc are in the beta phase. It is advisable, therefore, whenever the true character of an alloy is sought, to see that a specimen has been slowly cooled from the molten condition or that it has been subsequently annealed.

The melting or freezing point of alloys in the beta phase may be taken as about 860 deg. C. The beta alloys comprise those alloys having both the highest percentage of zinc and the lowest freezing point of the industrial copper-zinc

alloys. Except in those cases where the zinc is in part replaced by an appreciable quantity of aluminium and manganese, these alloys are liable to fracture under shock to a greater degree than the alloys of either the alpha or the alpha-beta series. When a beta metal is fractured, the rupture, in some cases, follows round the boundaries of the grains. It is from this fact that the grain size of the beta alloys appears to the uninformed to be coarser than the grain of a fractured alpha or alpha-beta alloy of the same grain size. When beta metals are very slowly cooled or annealed there is a tendency for the crystal grains to grow to a large size by absorption of adjacent crystals—with little mutual cohesion. Especially so is this the case if the metal has been subjected to the effect of chill or cold work previous to annealing. In such cases, the strength and ductility of the metal may be adversely affected.

The size of the grains in beta alloys is often variable over a small area, thus very fine and very coarse grains may appear abruptly side by side. This condition has only occasionally been observed in large castings of alpha-beta metal. By additions of small quantities of suitable metals, the yield and breaking loads of the beta class of alloy as-cast may be raised to 30 tons per sq. in. yield and to 55 tons per sq. in. break. Such high-tensile alloys are, however, very sensitive, and any slight out-of-balance in composition, or error in manipulation, may prove disastrous. Moreover, it must be borne in mind that with alloys of the beta category, a gamma phase immediately follows the beta, and the slightest error of judgment in compounding these alloys may result in the presence of traces of the very brittle gamma constituent, thus rendering the metal definitely useless for anything other than remelting. Alloys of the beta phase can best be worked hot.

Foundry Technique

"If one were called upon to arrange the non-ferrous alloys according to the ease with which they can be successfully compounded and cast, manganese bronze would certainly not be listed

near the top. In fact, many who have had dealings with this alloy would give it a place at the bottom, while some would go so far as to eliminate it altogether."—*Extract from contemporary journal.*

Manganese bronze, as a founding alloy, cannot be said to find universal favour. Admittedly, the successful founding of manganese bronze is not an easy proposition, as evidenced by the fact that even when the best foundry technique

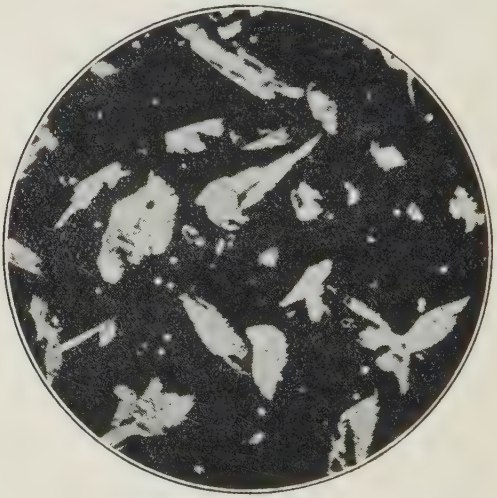


FIG. 5. — MANGANESE BRONZE, SHOWING A DUPLEX STRUCTURE OF ALPHA PLUS BETA (25 TO 30 PER CENT. ALPHA). × 100.

appears to have been followed, failures are not uncommon. Moreover, the proposition is one in which the remedial measures to be adopted to prevent a succession of failures do not readily suggest themselves. For the foregoing reasons, many non-ferrous founders consider they have justification for not being enamoured with manganese bronze, which, although grudgingly admitted by them to possess enhanced mechanical properties when compared with the best of the

ordinary bronzes, they couple with aluminium bronze and regard the two alloys as the ugly sisters of the foundry.

First and foremost, it is essential that the founder should have a well-balanced alloy, skilfully compounded under strict supervision both as regards temperature and melting conditions. Moreover, the alloy must be of such a composition as not only to meet specification requirements in respect of mechanical tests, but must

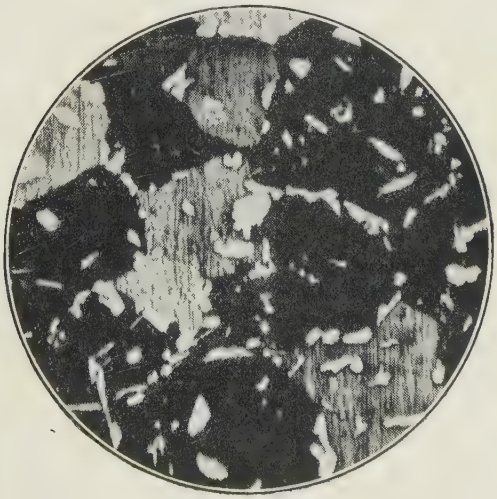


Fig. 6. — Manganese Bronze, showing a Duplex Structure of Alpha plus Beta (20 to 25 per cent. Alpha). × 100.

also have, as far as is possible, the desirable properties of a good casting alloy without which successful foundry production cannot be assured. As the author has previously stressed in a former Paper on the manufacture of marine propellers, it is easily possible, by employing unskilled labour, the adoption of careless methods, a laxity of supervision, or a lack of experience, to fall very far short of success in the manufacture of good manganese bronze. Abnormal

gassing, want of homogeneity in the mixing, high melting losses of one or more of the constituents, segregation and other troubles, are the defects often observable in an improperly compounded alloy. It is obvious, therefore, that the inexperienced founder attempting to compound such a complex alloy is severely handicapped, even before proceeding with the making of castings. It is for this reason that the author strongly advises that stock ingot metal be purchased from a reputable manufacturer. Manganese bronze, in ingot form, corrected for normal melting losses, complying with almost any specification within reason, together with reliable information as to the best melting temperature and range of casting temperatures for the particular grade of alloy, are readily procurable from trade sources. To those, however, who are interested in gleaning something about the recognised "best practice" observed in compounding manganese bronze, attention may be directed to the alloys now obtainable in the market, such as manganese-copper, ferro-zinc, cupro-nickel, etc., alloys which admit, at comparatively low temperatures, of the introduction of metals which in the un-alloyed state have a very high melting point.

The following details cover the foundry procedure which should be observed in the founding of manganese bronze: In general, a contraction allowance of $\frac{1}{8}$ to $\frac{3}{16}$ in. to the foot should be allowed on patterns. On surfaces of medium-size castings which have to be machined, the following machining allowances are advised: $\frac{1}{10}$ to $\frac{1}{8}$ in. on faces cast downwards, $\frac{1}{8}$ to $\frac{3}{16}$ in. on side faces, and $\frac{3}{16}$ to $\frac{3}{8}$ in. on top faces. Small castings may be cast in green sand, rammed fairly stiff, adequately vented, and dusted lightly with either lime or plumbago. Large castings should be made, preferably, in well-dried moulds; the surfaces lightly brushed with a thin coating of plumbago dressing, made up in the proportion of 2 lbs. blacklead, 1 oz. core gum and sufficient water to form a thin wash. All cores should be free venting. Surfaces that are required to be quite clean should, whenever

practicable, be cast face downwards. The use of denseners is, in some instances, almost imperative. Provision must be made for liberal feeding heads—these should be so located as to be most effective. All heads should be so fashioned and dimensioned as to preclude the possibility of a head "setting" prematurely before the casting itself is completely satisfied. Feeding with hot metal is often necessary, hence the advisability of keeping heads "open" with a "cover" of dry charcoal powder. Small runners should be employed. It is desirable, whenever possible, to "gate-in" at the bottom of a mould, the intake being as small as practicable having due regard to the proportionate size of the casting. When teeming, the down runner should be kept full of metal to exclude air. A dirt-trap or sump should be fashioned at the bottom of the down runner; this will serve also to prevent splashing and "shotting" of the molten metal as the alloy enters the actual mould.

For castings required to give the maximum tests, clean approved metal is essential. No scrap other than that of the same type should be used in admixture with new metal. Mixed clean scrap, such as heads, runners and ingotted swarf —the latter having been first magnetted before remelting—may be used in a proportion of two parts by weight of new metal to one of scrap. Manganese bronze in ingot form, as purchased from the trade, is corrected for normal melting losses, and, this being so, mixed metal charges of scrap and new metal, in the case of castings for which the maximum tests are not specified, will not require to be doctored by any "additions," providing that the above ratio of scrap to new metal is maintained, and that care is observed to avoid any abnormal "losses" by the undue exposure of the molten charge.

Small quantities of manganese bronze may be melted in plumbago crucibles either in coke-fired pot furnaces with natural draft, or in tilting furnaces of the usual type employed in non-ferrous metal melting. Large quantities can be more conveniently melted in open-hearth coal- or oil-fired reverberatory furnaces. When charging

a crucible, care must be taken that no metal projects above the top of the vessel. The charge may with advantage be "covered" with a few pieces of hot dried stick-charcoal. This precaution, however, may be dispensed with if the best melting technique is always observed. The charge should be melted at as low a temperature as is consistent with rapid melting. Every endeavour should be made to obtain the whole of the metal required for any one casting, or set

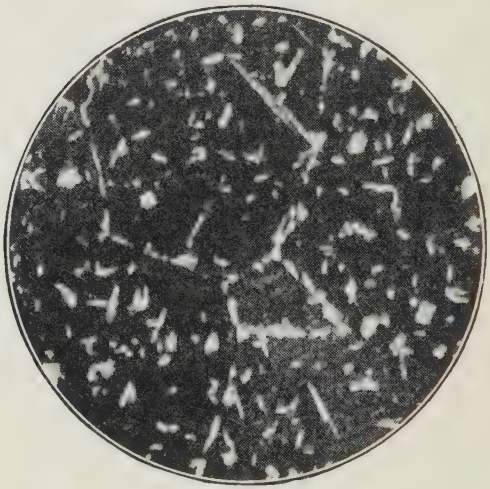


FIG. 7. — MANGANESE BRONZE, SHOWING A DUPLEX STRUCTURE OF ALPHA PLUS BETA (15 TO 20 PER CENT. ALPHA). × 100.

of castings, in the shortest time possible. The temperature during the melting operation should not, as a rule, exceed 980 deg. C., although a slightly higher temperature may be advisable when melting only small quantities in crucibles.

Manganese bronze is not improved by being held in a liquid state longer than is definitely necessary. Overheating of the metal must be studiously avoided, as must also too frequent or violent stirring of the molten metal. Inattention to the foregoing points, results, by undue

exposure of the melt, in gassing of the metal, the formation and inclusion of oxides, dross, etc., and, incidentally, to the alteration of the chemical composition of the alloy as originally compounded. Such happenings will seriously affect the mechanical properties of the bronze, and also the general soundness of a finished casting.

With some grades of manganese bronze, it is advisable to work to a fracture bar, in order

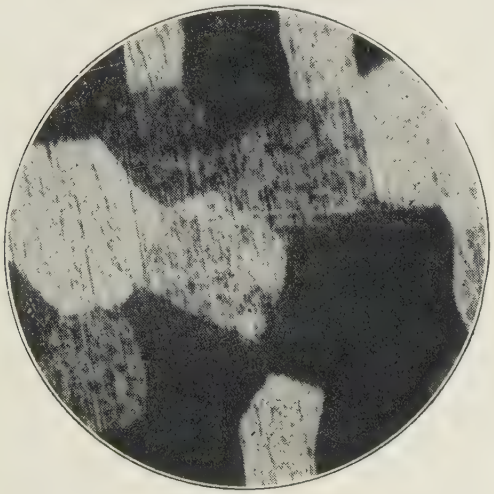


FIG. 8. — MANGANESE BRONZE, SHOWING A HOMOGENEOUS STRUCTURE, CONSISTING OF THE BETA CONSTITUENT. × 100.

to ensure that the melting losses have not been excessive, and also to serve as a guide in those cases where an addition of a small quantity of spelter, "to correct for loss," is deemed desirable. Standard fractures may be readily prepared by casting small quantities of a melt of well-mixed new ingot metal into small open-topped cast-iron moulds of the horizontal type. A small hand-ladle will suffice to convey sufficient metal from the bulk to fill a number of

such moulds. The bars cast therein when cooled-out and broken across the centre, will reveal the characteristic "after one remelt fracture" of the particular grade of bronze supplied by the manufacturer, and will serve as standards by which subsequent melts can be judged, and the desirability of making any "additions" determined. Obviously, the bars, in all cases, should be cast as nearly as possible of uniform size, and the cooling conditions should be standardised.

Whenever founding manganese bronze, the mould should at all times be ready to receive the molten metal as soon as the latter is run down. The casting temperature should be as low as practicable, consistent with a sufficiently fluid metal throughout the casting operation. The actual temperature of the metal will naturally depend, in a large measure, upon the weight, the nature and dimensions of the casting, also upon the method of running, the size of the runner and of the in-gate. The mean temperature for any grade of manganese bronze will be represented by a casting temperature of 960 deg. C. In the case of crucible melting, when more than one pot is used to run down the required quantity of metal, the contents of each pot should be transferred to a preheated, lined, shank, or ladle, before finally teeming the metal into the mould. By doing so one ensures that, after gentle rabbling, the metal is averaged in composition throughout the mass. The surface of the molten metal should be carefully skimmed free from dross, etc., the lip of the container should be brushed clean, and the temperature of the metal should be accurately determined by the insertion of a pyrometer. Skimming of the surface of the molten metal and temperature observations, in the case of larger charges from furnace tappings, are likewise desirable.

The founder must of necessity take into consideration not only the gross weight, but also the nature of the casting to be produced, particularly in regard to thickness of sections, area of surfaces, and the relation of heavy and light portions of the several parts. Whenever a large casting has to be poured, it is recommended that

a runner-box or boxes should be arranged above the runner, and of such capacity as to hold at least one-third of the gross weight of the actual casting. When adopting this contrivance, it is advantageous to use a ball-plug wherewith to close the runner temporarily, and, when the receptacle above referred to is full, to ráise the ball smoothly. The object of this arrangement is three-fold: firstly, good static pressure is available; secondly, it ensures that only clean metal enters the mould; thirdly, the down-runner can be kept full, and uniform pouring and the avoidance of much of the turbulence occasioned by the metal entering the mould can be ensured; freedom from entanglements of dross and "dead metal" thereby results, and the liability of the formation of "cold laps" is considerably reduced. Large moulds must be thoroughly dried, and after leaving the stove must be kept warm until immediately before the metal is teemed. The casting box must likewise be thoroughly dried and kept warm, the ball-plug being heated to redness and scaled if necessary.

The runner-box should be filled at the commencement of the pour; the level of the molten metal therein being kept constant for as long as practicable by a continuous flow of metal from the ladle, care being taken to see that the stream of metal does not impinge immediately over the orifice in the casting box.

Too rapid teeming of the metal into the mould must be guarded against and splashing avoided at all costs. A dry mould and a hot runner-box, rapid melting, careful skimming, correct casting temperature, good static pressure, slow, steady, continuous pouring, are pointers which lead to the production of sound castings.

When teeming a mould direct by hand, the lip of the container should be brought as near the mould as practicable, in order to avoid undue exposure of the molten metal. Large castings may with advantage be partially uncovered, and the mould relieved after the metal has completely set, in order to secure, by accelerated

cooling, as fine a grain structure as possible, and to ensure the absence of abnormal internal stresses in the casting. Consideration, however, must be given to the necessity of allowing sufficient time to elapse in order that all thin sections may continue to feed uninterruptedly from the thicker sections and not *vice versa*, and also to the possibility of distortion setting up at the junction of parts of unequal section.

When making provision for test-bars to be cast integral with a casting, the "pockets" should be so formed, and placed in such positions, as to be least likely to entrap dross or dirty metal in the bars.

London Branch.

SOME GENERAL REMARKS ON MECHANISED FOUNDRIES AND THE MAKING OF MOTOR CYLINDERS

By G. W. Brown, M.I.Mech.E. (Member)

This subject is a very live one, and has already been fairly well discussed from different views, but it is believed that there is much yet to be said, and particularly by the user. The plant and methods which are the subject matter of this Paper are as perhaps it is understood at the Austin Motor Company's works at Longbridge, and it is also generally known that the company has spent and is still spending considerable sums of money to accomplish the results desired, and it is very gratifying that they so willingly allow this material to be used for this Paper.

It is not intended to deal with the methods of moulding—as each foundry has to determine these according to their detail of manufacture—or to dwell on the metallurgical side, as this again varies with the detail of manufacture, but to give a general survey of ways and means and furnish material on which a discussion can be built. The mass, or production in large quantities of many varying details, has brought about the demand for methods whereby these can be handled more satisfactorily, and the more the mechanical engineer studies these requirements the more easily will the foundryman be able to furnish the results required.

Foundry work consists of a large number of details, each in its turn embodying an exasperating variability whether it be cast iron, steel, or non-ferrous, but the mechanical means and what it stands for can reduce these to a

considerable degree. The general conception of a mechanised foundry is that of a foundry as a mass of moving tracks, conveyors, belts, jigging screens, runways, and a conglomeration of mechanical details too numerous to absorb in a casual visit. A mechanised foundry, however, is the necessary, although belated, development, and a vital need, and the more help the foundries

Fig. 1.—Rotary Sand Drier of 2½ to 3 Tons per Hour Capacity.

give to the makers of foundry equipment the quicker mechanical development will be and the better the plant. The term is very elastic, and the simple roller conveyor for the moving of castings is a step in the direction, and part of the general scheme.

The demands of the production engineers for volume, with a high standard, at a lower price will force the development into a prominent place in the general schemes which constantly

occur in the lay-outs for production. The mere fact of mechanising a foundry will not give results unless it is accompanied by the control essential. The foundryman's attitude of rough and cheap equipment must change, and the ideas of putting the core-making in any old corner and under indifferent conditions will not have any place in the foundry of the future. Operations, as is common in the machine shop, will have to be split up and specialised.

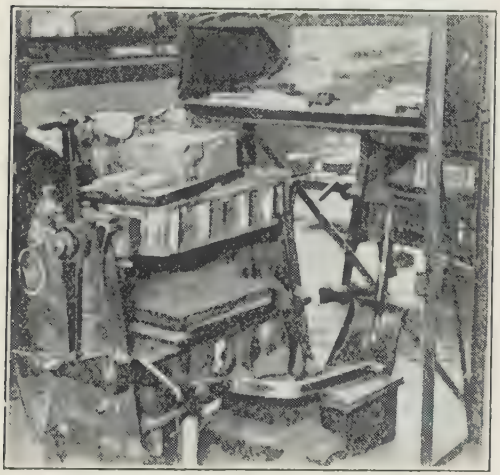


Fig. 2.—Showing Side-Bench Supply of Sand for Use with Moulding Machine.

The mechanised foundry is not replacing the skill of the foundryman; it requires greater skill and demands that it shall be applied at the proper place and at the proper time. The skill, however, must be in the visualising and in the laying out of the methods of production; in the equipment and supervision; in the close inspection of raw material; in the control of the metal melting and pouring; in the preparation of sand, and in the spirit of determination to reduce the variables to a minimum.

General Lay-out

The raw materials used in a grey-iron foundry are not easily or cheaply handled under any method, but they can be considerably reduced in cost by efficient and suitable methods. Pig-iron, scrap, coke, sand and limestone are details required in large bulk and are received in large lorries or railway trucks. One company built an inclined roadway from the main road to their cupola platform and all material was unloaded

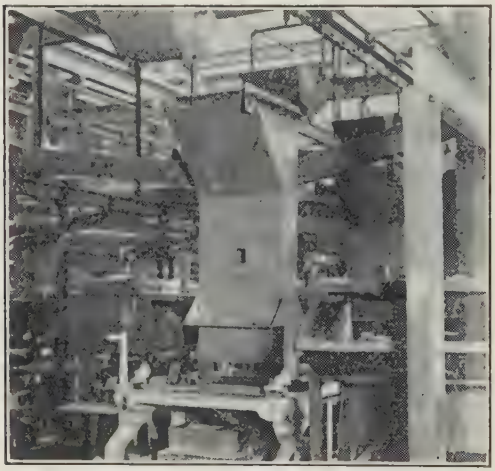


FIG. 3.—SHOWING HOW COREMAKERS' HOPPERS ARE SUPPLIED BY OVERHEAD BUCKET LINE.

at the same level as the cupola charging door, which eliminated at least two handlings.

The most common lay-outs, however, lend themselves to lifting the material. In the case of the pig-iron and scrap, a lifting magnet is desirable, and with the coke, sand and limestone, a bucket grab is a very quick method, but has one defect in so far as coke is concerned, and this method tends to break up the coke by the grabbing action and also in the releasing, and

quite a reasonable amount is lost as breeze and dust.

It is also advisable that the necessary tests are made on these materials before being unloaded if delivered by rail to the foundry siding, so that they can be returned if necessary or held separate until some arrangement is made with the suppliers. The storage and handling of these materials will be influenced by the space available, and also by the type of melting unit, whether cupola or rotary furnace. In the case

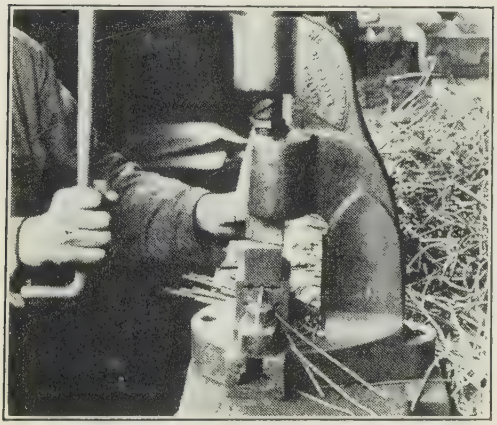


FIG. 4.—SMALL CORE-WIRE-STRAIGHTENING MACHINE ENGAGED ON RECLAMATION.

of the cupola, the material will require to be taken to the height of the charging door, while in the latter it will not be necessary to elevate it except to lift it for charging.

The raw materials should be near to their point of entering production, and further mention will be made of this as the different sections are dealt with.

Core-making Section

In some details, particularly in motor-cylinder manufacture, this might be termed the pivot on

which results swing, whilst in other classes of manufacture it will play a very secondary part regarding the lay-out, but will demand equal departmental results. The core sand should be stored under cover where it is easily accessible, and the floor should drain away from the place where supplies are drawn. Probably two or three different sands will be used, and these should be stored so that no complications arise through mixing the various types.

A large portion, if not all, of the sand will require to be dried, and this can be efficiently done in a simple rotary drier such as is shown in Fig. 1, the capacity of which is about $2\frac{1}{2}$ to 3

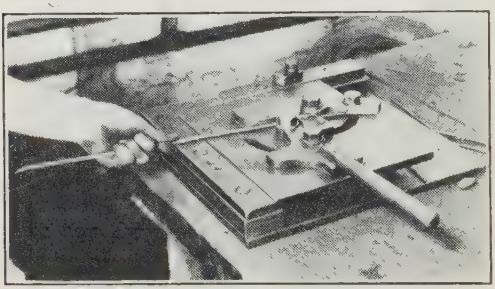


FIG. 5.—BENDING JIG FOR CORE WIRES.

tons per hr. The sand empties at a temperature of about 120 to 150 deg. C. Ample hopper, or floor-space capacity should be allowed for the sand to cool, and there is an opening for an effective sand-cooling arrangement, as sand will not cool very quickly stored in a hopper, and there appears to be only two conditions of sand, either cool and wet or dry and very hot as it comes out of the dryer. This can readily be understood when one realises that dry sand is split up immediately into particles and that it is a very delicate job to dry so small a particle as a sand grain without getting it very hot.

The mixing machines should be near the dryer, and so save unnecessary handling and transport.

These machines, speaking in a general way, are not designed sufficiently robust for their work, and it is perhaps due to the desire to keep them at a price acceptable to the general ideas of expenditure on foundry plant. There are, however, exceptions to the rule, and the tendency is one of improvement.

The supplying of the mixed sand to the operators is a very vexed one, and must be controlled by the volume required and the class of details made. Many lay-outs can be given, but in large-quantity production the chief object should be to save the operators' time.

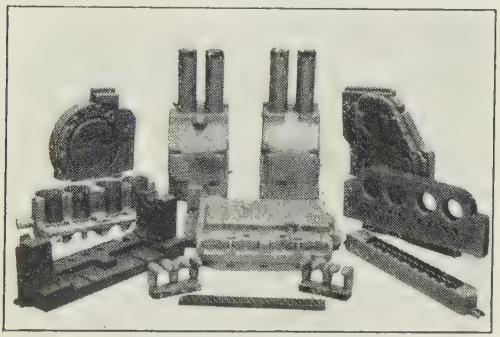


FIG. 6.—SET OF GAUGES USED IN CYLINDER MAKING.

It is common in modern lay-outs to mix on a balcony and feed the sand down shutes on to a table round which the operators work, and the sand is within arm's length. Another method is to take the sand and put it into bins near the operators; each operator may have a hopper attached to the bench and the supply is maintained, as shown in Fig. 2.

A further method in use is to take the sand round the core shop in an overhead conveyor, in tip-up buckets, so that the operator has simply to tip the bucket as it passes, and, when different mixtures are in use, the buckets are painted different colours. This is shown in Fig. 3.

The author's perspective will of necessity be largely controlled by the requirements of a plant dealing with cylinder castings, and the core shop of such a plant requires far more detailed consideration than is common in most details. For instance, in this particular shop, about 52,000 core wires are used daily, and this requires a section with the plant for preparing the wires ready for use and also, the organisation for reclaiming wires which pay to use over again.

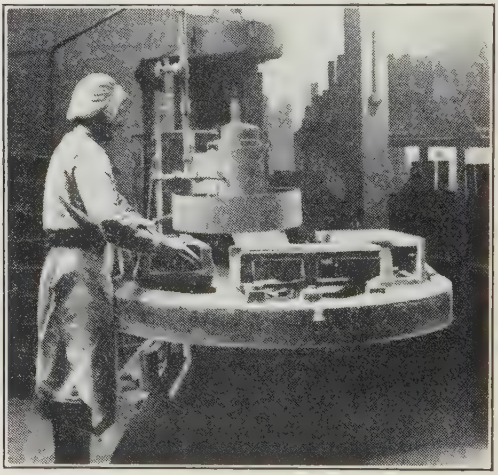


FIG. 7.—CORES FOR AUTOMOBILE WORK BEING GROUND TO SIZE.

An automatic cutting-off machine is kept in constant use, the heavier wires being cropped off under a power press. Reclaimed wires are straightened on the power machine, and also by the hand presses shown in Fig. 4, the latter being a simple, yet efficient, method. Simple bending jigs, which are shown in Fig. 5, are made for each particular wire, so that the core-maker is kept supplied with wires ready for putting in position. Grids have also to be developed, made, and reclaimed after use.

Quantity production coreboxes are of metal and these are daily checked and kept to size, and duplicate sets are ready for replacing when the boxes are worn. Large and deep draw boxes are put on simple turnover machines fitted with vibrators (Fig. 2), while the small and shallow draw boxes are made on the bench. Quite a large number of cores are of such a shape that dryers are necessary, and these require constant attention for keeping to shape and cleaning off the dried oil and sand. A de-greasing plant is being installed, and it is possible that this is an entirely new departure in foundry practice.

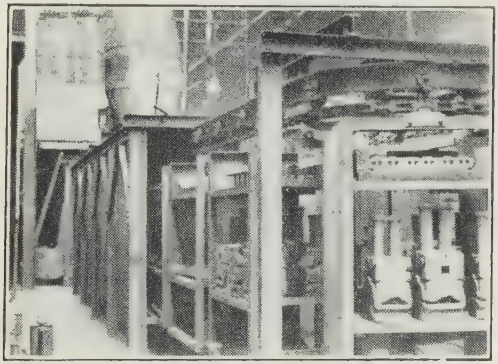


FIG. 8.—CONTINUOUS HORIZONTAL TYPE OF CORE STOVE.

Too much stress cannot be given to the design and upkeep of all coreboxes and dryers for cylinder making, where such vital items as thicknesses of cylinder bores are so very vital. In cylinder making, the finishing, gauging and assembly of the cores play a very important part, and the expenditure of gauges and tackle is well repaid. These are shown in Fig. 6. "Go" and "Not Go" gauges are used when necessary, the same as in a machine shop, and grinding machines and rubbing jigs (Fig. 7) are used on parts where they fit in assembly.

When finish is important, the cores are blacked either by spraying or dipping, after which they are again dried either in a continuous oven or an inclined roller conveyor, or in separate ovens. The horizontal stove (shown in Fig. 8) travels at $1\frac{3}{4}$ ft. per min., the drying chamber is 38 ft. long and the cooling chamber 19 ft. long. The part and purpose of each separate core, of course, determines its operations, and each,

Fig. 9.—Loading a Continuous Core-Drying Stove.

again, is subject to experiments and development.

Core Drying

Indifferent drying of cores can cause endless trouble and nothing is more annoying than to find faulty castings due to cores either over or insufficiently dried. The type of core stove required will depend on the volume and details made—methods of taking to and away from the stoves, or, in other words, the lay-out of the core shop. Stoves can be oil-, gas-, or coke-fired, and makers' claims differ in their

application. The stoves can be put under two types, fixed and continuous, while the latter can be either vertical or horizontal.

The fixed type are usually fed with portable racks which are filled near to the operators and either lifted bodily by an overhead crane and placed on rails leading into the ovens, or lifted by a lifting truck, either electric or hand operated, and taken direct into the ovens. A lengthy experience has shown that cores cannot be equally dried in this type, as it is usual for the inlet flues to be on the floor at the side, and

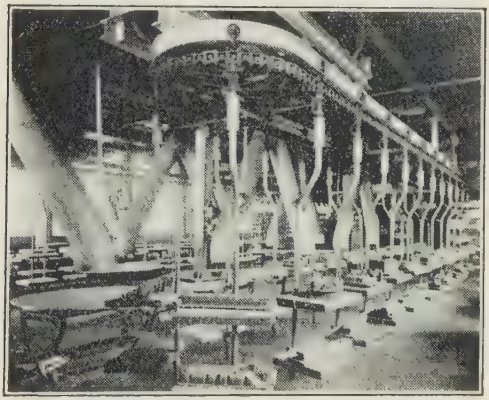


FIG. 10.—PENDULUM TYPE OF CONVEYOR SERVING CORE STOVES.

the natural, induced, or forced flow of the heat cannot be equal throughout the area occupied by the cores, and therefore discretion has to be applied in the loading of the racks so that the larger cores will be placed where they will get the most heat and the smaller cores the least.

In the continuous type, different conditions prevail, and the core is subject to a rising and falling temperature, *i.e.*, as it enters and leaves, and the oven can be made large enough to subject the cores to a cooling system whereby they can be handled immediately they leave the oven.

and, in addition, most of the fumes have been dispersed, making the conditions of the shop much more congenial. It would appear that the continuous vertical type has much to commend it over the horizontal type, chief of which is the smaller floor space required and the simple means whereby the cores can be subjected to the rising heat which appears to indicate a more economical drying. Such a stove is shown in Fig. 9. The number of cores dried per day is about 17,000, with a total weight of 25 to 30 tons, the individual weight ranging from 2 ozs. to 48 lbs.

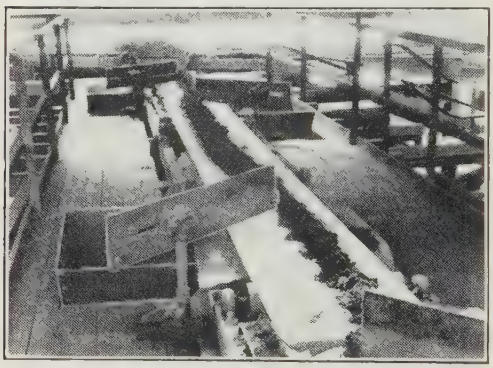


Fig. 11.—Showing Method Adopted for Scraping off Sand from a Belt Conveyor.

In the lay-out for the continuous type, a belt or pendulum conveyor is usually employed for taking the cores to and from the ovens. This conveyor (Fig. 10) travels at 21 ft. per min. Particular attention is necessary for the ventilating of the shop, especially taking into consideration the placing of racks of cooling cores where no arrangement is made in the ovens. In the lay-out of the core shop, provision must be made for some storage space, both to allow for detail cores before assembly and a buffer stock for supplying the moulding section.

It is, of course, desirable to keep this to a minimum, but unless some provision is made much delay and confusion will result. Needless to say, the less a core is handled the better, and crowding or packing on trays or conveyors will result in cores rubbed below size or out of shape, and a large proportion chipped or broken.

In cylinder-making, the cores can be delivered to the moulding section either assembled in sets or part assembled on portable racks, belt, or pendulum conveyors, but it must not be overlooked that the cores will require to be taken

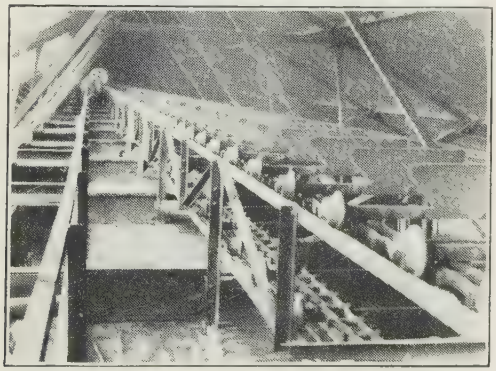


Fig. 12.—Flight of Scraper Conveyor Feeding Sand Hoppers.

apart again and blown clean before putting into the mould, and therefore some arrangement should be made for this near the moulding section; this can be done by supplying small benches fitted with air pipes with reduced pressure. Experience has shown that often dirty castings can be traced to the too liberal use of the air pipe with high pressure.

Moulding Section

This will require dealing with in two parts, sand mixing and supply plant, and the lay-out

of moulding machines and mould conveyors. The development of the science of moulding sands is progressing fast, and to the study of the requirements and the results desired too much time and attention cannot be given; where it is possible, it should be under specialised control. It is essential that the sand be delivered in a consistent state, milled and tempered in a uniform manner. The finished sand should be tested at least every hour, and the results posted so that the different executives can see the results at a glance. Table I represents such a system. The tests should be for moisture, strength and permeability, and it will be found possible to keep these reasonably constant.

TABLE I.—*Tabular Representation of Blackboard as it appeared on the afternoon of April* 16, 1934.
Sand.

	Facing.			Backing.		
Time.	Vent.	Bond.	Moist.	Vent.	Bond.	Moist.
8.45	60	8.1	4.5	66	5.4	4.0
9.30	60	8.0	4.5	66	6.0	4.0
10.50	60	8.5	4.4	68	6.5	3.9
11.35	60	8.2	4.6	66	5.8	4.0
1.40	56	8.4	4.8	66	6.5	3.8
2.30	56	9.0	4.4	60	6.2	3.7

The mixing mills should be adjusted and kept in a state that uniform results can be obtained. The rollers should be set so that no grinding action is possible, and the shoes or ploughs sweeping clean and constant. The milling time can be determined and a time clock be used for each mixing. The old sand can be taken up to an overhead hopper, and the setting of a belt conveyor will deliver to the mill the same amount for each mix. These mills can be set in pairs so that, while one is discharging, the other can be mixing.

It is necessary that a disintegrator or aerator be put where the sand can pass through before being delivered to the machines. The method for conveying the sand to the machines appears

to give more trouble in settling than other parts of the plant. The problem depends on the space available. An overhead supply into hoppers is desirable, and whether it is supplied in bulk into the hoppers or by belt or push plate conveyor, can only be determined in each particular lay-out. It is very easy to fall into the state of mind that a complicated mechanism is neces-

Fig. 13.—Locating Cores in Moulds.

sary when a simple application would give better results.

A belt conveyor is clean, but care must be taken to see that the sand is dropped on the centre of the belt and not on one side. A piece of flash or a nail jammed at any point can, however, rip a belt costing £20 into shreds in a few minutes, and care should be taken to see the sand is free from these and similar items. It is also possible to set the ploughs sweeping the sand

into the hoppers to give a more positive supply to each machine than with the push plate conveyor. This is shown in Fig. 11.

The push plate conveyor, shown in Fig. 12, gives a larger spillage unless some means are adopted of supplying the sand to the plate in a consistent supply. Overhead conveyors should have a plate or dustproof protection underneath where they are situated over the machines or operators, so that it is not possible for any sand to drop into the moulds or on to the operators'

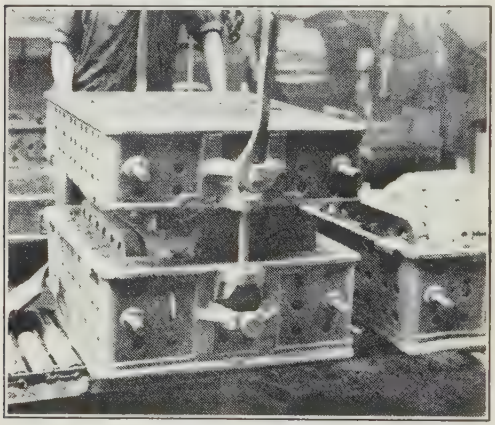


Fig. 14.—Showing Method used for Closing the Moulds.

heads. Hoppers over the machines should be set at such an angle that the sand will readily fall, and not pack in any way and entail knocking or rapping by the operators.

In some classes of details manufactured, a separate facing sand may not be necessary, or the detail and boxes may be of such a size that a facing sand only can be used. When it is required in addition, it can be put through a separate mill and carried on a belt running alongside the main one and fed into additional hoppers, or it can be put through the same mills, carried along the same belt and ploughed

off into additional hoppers feeding into a bin or into barrows, and wheeled round to each machine.

Mould Conveyor and Machines

These items are less general and can only be dealt with in detail for a particular line of manufacture. The machines require to be placed so that the mould can be easily placed on the track either by hand or crane. The amount of coring-up to be done will determine the position of the machine making the drags and the copes. Again, whether the coring-up is done before or after the mould is put on the track, will determine the position of the machines to each other. The size of the boxes will, to some extent, control the type of conveyor. The flat or plate conveyor is more suitable for heavy moulds and the pendulum for the lighter ones.

Coring-up can be done more safely on the plate type, the drag part being made and placed on the conveyor, and the cores placed while it is travelling to where the machine for making the cope is placed. After the cope is put on, travel has to be allowed for the boxes to be clipped or bolted, and runner bush put on ready for pouring. It is advisable with this type of conveyor not to fix the pouring station near to the end of the conveyor, where the driving gear or driven gear is placed, or splashes of metal and run-outs are liable to get in and cause stoppages, but with a conveyor driven through gear underneath, this is avoided.

When the mould is of such a size that bottom venting is necessary, a loose perforated plate can be placed on the track plate, being made so that there is necessary clearance between the two plates. It was found that steel plates on the track distort with the heat of the mould, and that cast-iron plates cracked through the same reason, so that loose plate now fills the dual *rôle*, *i.e.*, preserves the track plate and allows venting. The track for cylinder blocks travels at $2\frac{3}{4}$ ft. per min. and the track for cylinder heads at $5\frac{1}{2}$ ft. per min.

In this particular lay-out, shown in Fig. 9, the machines are placed together with a small length of roller conveyor between. The drag is made and placed on the conveyor on which the complete coring-up is done, after which the cope is put on, boxes clipped, and then the completed mould is lifted by a jib crane and placed on the track or by hand where weight allows.

The cores are first placed in a metal jig which locates each core in its relative position in the mould, the whole assembly then being lifted by

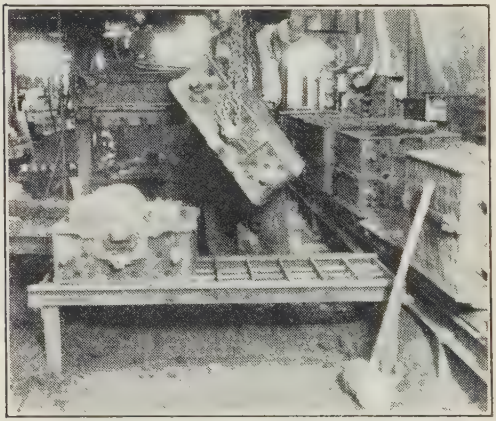


Fig. 15.—Knock-out Station over Grid.

a frame and placed in the mould, after which the frame is taken off and a final jig put on which holds the cores in position until they are finally ready for the cope, as is shown in Figs. 13 and 14. The pouring station will naturally be fixed in conjunction with the position of the cupolas or melting unit, so that the metal can be poured as hot as is required. Particular attention should be paid to the length of travel of the conveyor over which the moulds can be poured, and ample allowance given so that the conveyor has not to be stopped to wait for metal, otherwise the moulding is also arrested.

After the moulds are cast, provision can be made for the copes to be lifted before the final knock-out if necessary, as in the case of large castings the cooling of the castings will help in the final knock-out. The runner bush and risers, also box clips, can be taken off. In small castings this point will not be so important, but it will help to split up the operations and give the opportunity of directing this half-box back to its machine and in a cooler condition than if allowed to travel the full distance to the knock-out.

Knock-Out

The lay-out of the final knock-out is a perplexing study. Ample space should be allowed for the operators, and a large floor grid through which the sand can pass back to the system (Fig. 15). Under old foundry methods it was usual to have a knock-out gang operating at night or early morning so that the shop is clear for the moulders, and the floor space available. The castings when being knocked out are also relatively cool according to their weight, which enables the gang to operate under better conditions than under mechanised ones, unless special attention is given.

It will be realised that with a mechanical track the casting is knocked out as soon as possible, or after final graphitisation has taken place; therefore, in the operation there is a volume of steam and dust from the hot sand which, in addition to the heat from the casting, can create conditions very unpleasant and which require ventilation. In this lay-out, a stream of air is blown across the boxes which takes away the steam, and this is then taken out of the building by a large propeller-type fan.

A magnetic pulley or separator is necessary to remove all metal, nails and wires before the sand passes into the hoppers previous to the milling operation. The size and weight of the casting will determine whether any lifting tackle is required and how the casting is to be passed on to the next operation. Castings can be taken away on trays lifted by an electric truck, or on a

conveyor, overhead or roller. How to get the boxes back to the machine is another troublesome item. This can be done by putting them back again on the track after knock-out, in which case provision must be made near the machines for lifting off, or they can be returned by roller conveyor or overhead, and the author would suggest an extremely cautious deliberation on this matter before final action. Methods of knocking out the castings require careful consideration, and complicated methods should be avoided.

When the details and boxes are light, simple hand methods are probably the quickest and cheapest, and when they are too heavy for lifting by hand, a pusher rod can be used for pushing the box off the conveyor on to a vibrating grid, or electric or air blocks can be used to lift them on to the grid. It was found that a suspended vibrating yoke was too slow and cumbersome and that it was quicker for the men to knock the sand out of the box with a mallet. Particular mention must be made that, in the design of conveyors and tracks, some method of slipping device or shear pins should be included, and also a system whereby the stretch of chains can be taken up.

Fettling and Cleaning

Conditions will vary considerably under this heading according to the details of manufacture, and it is proposed to deal solely with cylinder blocks which perhaps entail as much in relation to weight as any detail to be found. In this particular case, the blocks are conveyed on trays to a knock-out space where they are allowed to cool for the next operation. This operation consists of knocking off the runners and cleaning out the cores where possible.

The blocks are then put into tumbling barrels (Fig. 16), either by hand or air block, according to weight, and these are packed with old tyres, cut up, and a very liberal supply of stars is added. The barrels are run for one hour, and the longer in the barrel the better the finish,

but as there is a subsequent operation of sand-blasting, a prolonged period is not necessary. After being taken out of the barrels, the blocks are placed on a roller conveyor and checked for defects, and the jacket-core wires are pulled out. The blocks are then pushed down the conveyor to the next operator, who, with a pneumatic chisel, chips off all edges and flashes, after which the blocks pass under a swing grinder (Fig. 17), which grinds the top face and the bottom flanges.

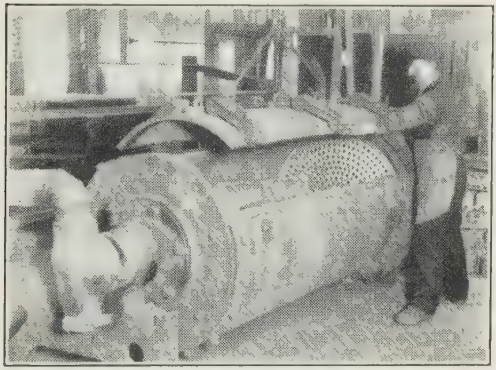


Fig. 16.—Old Rubber Tyres are Packed with Cylinder Blocks in this Tumbling Barrel for Cleaning.

Still passing down the conveyor, the next operator, with a portable pneumatic grinder, grinds the places where the chisel was applied and trims the blocks where necessary. The block is then either passed into the sand-blast chamber by hand, or lifted by a quick rope block on to special hooks on a runway, and, after blasting, is pushed out the other side of the chamber. The block is then passed to the benches, where it is sounded for bits of wire or metal in the water jacket, and finally dressed off with hand tools, except for the port holes, which are rifled out with a pneumatic portable rifler.

The casting is then passed to the foundry inspectors, who again check for wire and metal in the jacket, inspect the general finish of the block and check for thickness of metal, position of the bearings and ports. The final operation is the jigging of the block for machining operations (Fig. 18), which operation calls for special control and understanding.

This section cannot be passed without some mention of the mechanical means necessary for dealing with the sand wires and grids knocked off the castings as they come from the track.

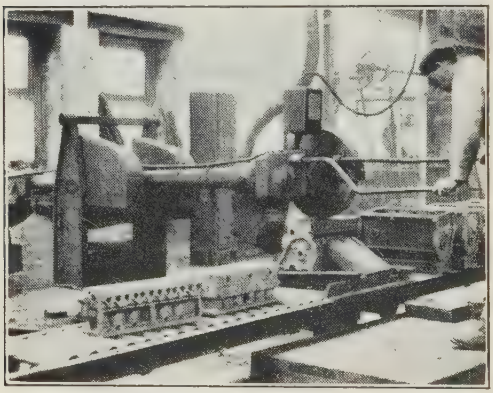


Fig. 17.—Swing Grinders are used for Dressing Cylinder Blocks.

Grids and wires are reclaimed, and these can readily be picked out by hand. The metal from runners, risers and flashes, however, need to be separated, the large pieces by hand and the small, either by a magnetic separator or riddled, and, when it is possible, this can be coupled with an elevator to take the sand direct into skips or trucks, or the whole can be fed through a grating either into trucks or on to a conveyor for disposal to a tip or for use again. A dust-removal plant will also be necessary for two reasons—to clear the section and prevent

spreading to others, and, if the sand is for use again, to prevent loss of permeability.

Melting Plant

As in the making of a motor car, the results are dependent on a thousand and one details, any one of which can mar the others, so in a foundry all the details require to be in their correct time, place, and condition to ensure a good casting, and one of the most vital items is the metal. This Paper was not intended to deal with the metallurgical side, but mention must be made that in the casting of cylinder blocks the metal control should be as close as it is possible to maintain it. The cupola is still perhaps the most suitable and economical melting unit for grey iron, even with alloys, especially where a continuous supply is required as in the case of a mould conveyor. The rotary furnaces, either oil, electric, or pulverised fuel, do not appear to be suitable for this system unless a number of these are in use to tap at definite intervals, or a duplexing system followed.

In the foundry with which the author is associated cupolas are used, details of the general lay-out are as follow:—The materials, such as coke, limestone, pig and scrap, are lifted into bins on the charging floor by mechanical grab in the case of the coke and limestone, and a magnet for the pig and scrap. The magnet is shown in Fig. 19. The railway trucks run alongside the foundry, and the crane passes over the trucks running on rails outside the truck rails. The materials are then placed on a weighing scale running parallel with the front of the bins, and charged by hand into the cupola.

The platform is fitted with a mechanical charger controlled by air, and then the material is placed in a bucket resting on the scales. The bucket holding the charge is then allowed to slide down a cantilever frame into the mouth of the cupola, and the drop-bottom of the bucket is actuated and opened, allowing the charge to fall into the cupola. It will naturally be asked

why this method has not been continued, the reason being that it was considered the analysis was too variable, and a changeover to hand-charging gave immediately more consistent results.

The author is of the opinion that the door at the bottom of the bucket being only a single door, allowed the materials, *i.e.*, coke, pig, limestone and scrap, to mix in the dropping and that a double door which opened at the middle would maintain the charges in their respective position. In addition, he would not advocate a bucket charger for a cupola under about 36 in. internal diameter. Before leaving the cupola platform, it is perhaps advisable to mention that a hoist should also be put in as a standby to the outside crane and as a means of taking up auxiliary materials.

The tapping end of the cupola requires expert control, as any mishap or delay means that moulds cannot be poured, and this in turn means that moulds cannot be knocked out, and therefore, if moulds are made, there is no empty plate in the tracks to put them and they in turn cannot take the cores from the core shop, and so any hold-up means a complete one or absolute dislocation. The tapping control should be most thorough, and hard holes, run-outs, patching spout and all the irritating incidents which can happen, should be guarded against. In cupolas melting iron for cylinder blocks, a constant melting speed should be maintained, and particularly no slowing-down allowed.

Slow melting increases the carbon and sulphur pick-up, both of which cause soak or draw, resulting in what is termed "open metal." This invariably shows in the bores of the cylinders near to the junction of the barrel and the water jacket, and also in the valve pockets; in addition, the same trouble will be found in the cylinder head bolt-holes, causing leaking castings. The whole control of metal and cupolas is another item which demands specialised supervision.

If there are no moulds, the metal should be tapped and pigged, for which a number of metal-

pig moulds should be placed nearby or a pig conveyor can be installed which will deliver the pigs direct to the charging floor. It is desirable that constant tests of the metal be made, and the more made the closer control possible.

A test mould should be near to the conveyor giving a bar (Fig. 20) from which can be determined fracture, chill, shrink, and Brinell hardness, the particulars of which are then entered

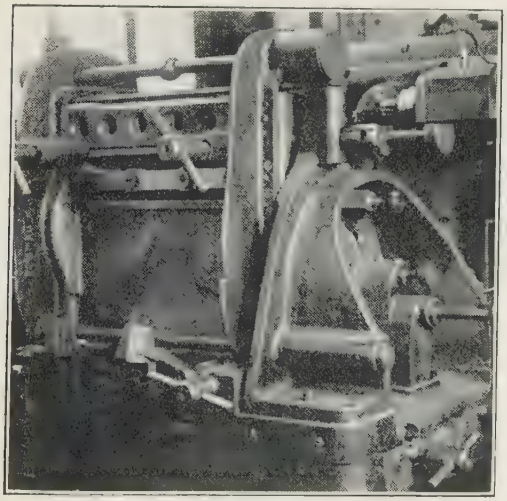


FIG. 18.—A JIG ASSEMBLY FOR MAKING THE SPOTTING MARKS FOR MACHINERY.

on a board, shown in Table II. It has also been found very useful to check the metal temperature or the temperature of the metal at which the mould is poured by timing the setting of the metal in the runner bush. Each mould is numbered consecutively with a stamp, so that the casting will bear this number. The moulding box has the corresponding number chalked on the outside, and as each mould is poured a stopwatch is used to record the time the pouring

ceased, and later, the time the metal in the runner bush set.

From this, it is possible to check the consistency of the melting and pouring temperatures and the records eliminate all arguments concerning cold shuts arising from dull iron and also metal burning in. The cupola should be as near to the pouring station as possible, and the ladles can be taken to that position on a single rail suspended on a pulley block, either chain or electrically controlled. In the case of a chain block, an asbestos guard or shield can be fitted above the hook which prevents the loose chain from being suspended in the ladle and causing

TABLE II.—*Tabular Representation of Blackboard Controlling Composition Test-Bar Physical Constants. Day, Monday. Date, April* 16, 1934.

No.	150-170 Shrink.	14-28-32 Chill.	Time.	Grey fracture.	255 max. Brinell.
1	0.157	21	8.45	M 1	228
2	0.155	26	9.40	M 2-3	235
3	0.159	24	10.10	M 1-2	241
4	0.157	20	11.0	M 1	248
5	0.164	21	11.30	G	241
6	0.161	25	12.15	M 3-4	
7	0.168	14	1.50	G	
8	0.160	21	3.0	M 1	
9					

undue stretch in working. The pulley blocks should be quick acting in raising and lowering, and the runner carrying the blocks capable of easy running and free on rail bends.

The position of the rail to the conveyor will be determined by the size or sizes of the moulds, and where more than one is made, the rail will require to be set to pour the largest, and the smaller moulds can be placed on the conveyor to suit. If it is possible, the rail should be of the one-way type, *i.e.*, the ladle should not have to be taken back to the cupola along the track it has already traversed, so that it does not interfere with another ladle, but if this lay-out

is not possible, then loops or standing stations should be provided for.

Consideration is necessary for the position of the operator skimming the ladle at the pouring of the mould, and any other operators assisting, which will be controlled chiefly by the class of work and sizes of moulds.

Conclusions

It is hoped that the foregoing particulars have

Fig. 19.—Magnet Hoist for Charging.

helped to illustrate that the chief feature necessary for the desired results is synchronisation, or, as it may be put, balance must be kept. As in the machine shops or any other department laid out for continuous progress and single operations, a breakdown of one unit holds up the whole sequence, and a foundry laid out on similar lines is subject to the same loss plus the one arising out of molten metal, as metal having to be poured into pigs loses immediately its value, and cannot again be made suitable except

at additional cost. It is also hoped that enough has been said to indicate that quicker, cheaper and better production is possible.

It is quicker by the mere fact of splitting up the operations. It is cheaper for many reasons. Firstly, there are less moulding boxes and tackle required and less space, less labour for handling materials, such as sand, boxes and castings. It gives better-quality production, because such a system requires the detailed supervision throughout the whole methods of production, such as raw material, control, sand analysis and metal control, high standard of

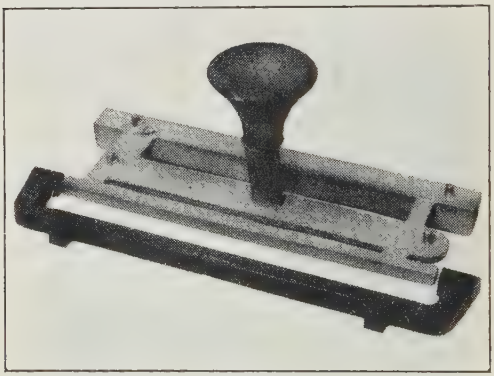


Fig. 20.—Test-Bar with Runner attached used for Shrinkage Test.

equipment, such as patterns and coreboxes, and the gauging and checking of the details.

There is immense scope in the foundry for the mechanical engineer, and in large foundries it is possible to study the different operations or branches in detail while taking part in production, as the larger the foundry the more the control will be split up, and the higher the specialised skill or knowledge will be in departmental control.

It is advisable that foundrymen, particularly controllers, should have a sound mechanical

knowledge, so that they can more easily understand the subsequent operations on the castings, and the uses to which they are ultimately put.

In the same way, designers and machine-shop supervisors could be more effective in their particular branch if it was possible for them to get some practical foundry experience, and similar knowledge in the designing for machining purposes could be applied to the moulding.

It is not an easy matter for a foundryman to influence designers and the engineers responsible for machine-shop lay-outs to effect alterations to suit the moulding, as sometimes it may mean additional parts to be made and additional machines purchased, while, had the details been designed with a foundry experience equal to that of machining, probably a detail would have been made more suitable for moulding. In the foundry with which the author is associated, a similar bonus system to that common in other departments is used, *i.e.*, operations are timed and individual piece-work or bonus is applied where possible. This systematically arouses the interest of the efficiency engineers, and it is now being accepted by them as their part of the foundry control with the necessary rate-fixers in attendance. Such a system also allows for a closer detail costing of each article produced.

In conclusion, the speaker wishes to express his thanks to the Austin Motor Company, and Mr. Hannay, the production manager; also to the following for loan of lantern slides:—Controlled Heat & Air Company, Limited; Bagshawe & Company, Limited; Herbert Morris, Limited; the Foundry & Engineering Company, Limited; Fordath Engineering Company, Limited August's, Limited; and Pneulec, Limited.

APPENDIX

STRICKLE MOULDING OF LARGE CASTINGS

By H. Fabre and H. Dubois

(*See page* 249.)

Since this Paper was presented at the Sheffield Conference, the death has occurred of Mr. Henri Fabre, one of the Joint Authors. The following reply to the Discussion has been prepared by Mr. H. Dubois.

AUTHOR'S REPLY

I thank my colleagues in the Institute of British Foundrymen for the interest they have shown in the Paper written by the late Mr. Fabre and myself, and which was presented to the Sheffield Conference.

The discussion, which followed, showed that the foundryman's keenness for his profession is still strong. As was pointed out at the beginning of the Paper, it was only intended to give a few practical examples and to use the framework, thus given, as a basis for the fundamental information disclosed—that is, the study of process. To do more would have occupied far too much space. They could, thus, only defend their position by generalities, for their object was to popularise the principles of strickle moulding by illustrating it under diverse conditions.

The most important observations arising in the discussion were principally related to the moulding of the black pot. This was most interesting, since, with this particular case, one could include every case of moulding of containers. The precautions to take, in order to get good results from these castings, are to a large extent independent of their weight and size.

(1) *Is a single layer of bricks sufficient for the upper part of the core?* Practice confirms that this is so. Brickwork carried out in the manner indicated in the Paper is, because of the shape of the mould, exceedingly strong. In the case of rectangular containers, this strength should be reinforced by the ramming of sand in the interior of the core when assembling.

(2) *Arrangement of the Runners for the Black Pot.*—A very important fact should here be noted. It is that containers of this type are destined for the chemical industry and that their use must satisfy a large number of operations in industrial chemistry. It is thus essential to obtain castings free from porous or segregated parts. A casting made in special corrosion-resisting iron must be definitely homogeneous and be free from zones liable to set up premature corrosion. To fulfil these conditions, the runner feeding directly into the mould cavity has given, up to now, the best results. The casting is run from a circular filter basin, placed on the upper part of the mould and forms numerous channels of which the total section corresponds to the calculation that has been outlined in the Paper. The basin being kept full from the start, there is no need to fear the introduction of slag, which can be incorporated with the core, and will thus set up zones of corrosion and, consequently, cause the rejection of the casting.

(3) *Contraction.* — Special precautions are taken to avoid the results of contraction. They should be the greater, as the metal gives higher contraction than that of ordinary iron—about 15 millimetres. The annular plates, which form the armature of the core, should have, in the case of castings of large diameter, a diameter of at least 20 centimetres less than that of the castings. At the same time, the thickness of the layer of loam, which surrounds the bricks, should be adequate. However, if care is taken to place at 120 deg., along the top of the core, three rows of loam bricks, which can be taken

away by knocking off after casting, and in addition the loam bricks at 120 deg. result in the production of a perfectly round casting.

(4) *Freeing the Core Gas.*—This is carried out in a very simple manner, since numerous vents are taken off between the bricks. The gas is lighted during casting, and, as a result, its evacuation is perfect.

(5) *Cost of Tackle.*—In the case of the moulding of a one-off job, the cost of tackle will, undoubtedly, be a very important item in the cost price; but it will always be lower than the cost of a complete pattern. On the other hand, as there are but a very few foundries specialising in loam moulding the amortisation of tackle is, as an actual fact, carried over to a large number of similar castings.

Finally, the author thanks his British colleagues for the questions they have asked, and he assures them that he is still at their disposal for any further information of which they may find themselves in need.

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